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MANIKIN TEST AND CALIBRATION SYSTEM PHASE I

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13. ABSTRACT *(Maximum 200 words)*

The objective of this project is to develop a test fixture to facilitate dynamic testing and system-level calibrations of an anthropomorphic manikin vertebral column and head complex. The calibration fixture is necessary to evaluate and improve the predictive consistency of the systems-level biofidelic performance of a test manikin under conditions of loadings that are encountered in ejection and crash environments. An optimal design arrangement to meet the calibration requirements is provided by this Phase I report. The fixture design provides controlled, accurate and repeatable excitations to produce consistent and reliable calibrations. Additionally, the fixture design provides the versatility to conduct short duration dynamic tests of aircrew interaction with various seating and restraint systems designed for ejection or crash conditions. The fixture design incorporates computer interface for input of test parameters and a pneumatic and hydraulic drive system to provide programming of the acceleration profile. The dynamic system provides significantly improved calibration over the current static techniques. This dynamic calibration capability is essential to obtain manikin test results that are repeatable and allow the comparison of one set of test results with another. Improved manikin calibration is particularly important for the reliable evaluation of life support equipment.

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MANIKIN TEST AND CALIBRATION SYSTEM
PHASE I

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October 1996

PHASE I FINAL REPORT

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EXECUTIVE SUMMARY

The objective of this program is the development and fabrication of a manikin system test/calibration fixture to facilitate the dynamic testing and system-level calibrations of the anthropomorphic vertebral column and head complex systems of assembled test manikins. Dynamic calibration of the manikin systems are needed to properly evaluate the aviator injury potential resulting from the performance of aircraft ejection systems and crashworthy seating. The development of the manikin system test/calibration fixture is necessary in order to evaluate and improve the predictive consistency of the systems-level biofidelic performance of test manikins under the conditions of dynamic loading that are encountered in ejection and crash environments. To obtain manikin system test results that are repeatable and allow the comparison of one set of test results with another, the need for a test/calibration fixture is clearly apparent.

An optimal conceptual fixture design for satisfying the test/calibration requirements is presented in this Phase I report. It is selected from a through review of system requirements and alternatives. A number of alternative configurations and drive arrangements, with computer interfacing for the input of test parameters, and a pneumatic and hydraulic system for drive and control of the test, are evaluated in this report.

A detailed conceptual design for the optimal concept of the "Manikin System Test/Calibration Fixture" is documented in this Phase I program. The design arrangement is selected and formulated in accordance with the parameters and specifications defined by a review of the NAWCAD calibration and testing requirements for test manikins. The recommended design incorporates programmable test and calibration parameters and is capable of reproducing specified acceleration forces and acceleration onset rates. A description and proof of concept for the recommended arrangement is provided in section 8.0 of this report. Detailed conceptual layouts for the overall assembly, and a cross sectional view of the assembled test/calibration unit, are presented in Appendix "A" of this report.

The recommended fixture arrangement will provide programmable, accurate and repeatable excitations that will allow the development of a controlled reference for the reliable and improved comparison of the test data obtained from expensive full scale field testing. Additionally, the fixture will provide the versatility to conduct short duration dynamic tests of aircrew interaction with various seating and restraint systems designed for ejection or crash conditions.

Fabrication of the "Manikin System Test/Calibration Fixture" presented by this report is recommended in order to accomplish dynamic calibration and short duration testing. The detailed conceptual design, recommended by this Phase I report, is capable of satisfying all of the parameters and specifications established for the manikin test system.

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1.0 INTRODUCTION

The evaluation of ejection and crashworthy seating systems has traditionally been accomplished on track and tower tests which utilize instrumented, biofidelic manikins as human surrogates for evaluating system performance and human tolerance. The common sensor arrangement for ejection and crashworthy seating tests includes six degree-of-freedom (6DOF) loadcells in the upper neck, lower neck, thoracic, and lumbar regions, and various triaxial arrangements of accelerometers in the head and thorax. The data generated in these tests is correlated to experimental human test, or cadaver data, in an attempt to assess injury mechanisms and potentials, and as a validation criteria of manikin biodynamic response. In addition to historical data, recent studies of fixed performance ejection and crashworthy seating systems to accommodate smaller and lighter aircrew have demonstrated that potentially injurious levels of acceleration exist for these occupants.

The overall safety of aviators in military aircraft has been improved continually over the past 25 years. For fixed-wing aircraft, current multi-mode, rapidly sequenced ejection systems have been developed to reduce the non-combat injuries and fatalities. The injury potential still exists, however, and in a comprehensive review of literature to date on aircraft ejections, Bowman [Bowman, 1993] states that Navy and Air Force researchers judged that ejection forces were responsible for primary injuries in 62 to 84 percent of major injury cases; the corresponding numbers for windblast and parachute opening shock were reported to be 28 to 10 percent, respectively. The dominant and most severe injuries that occur during escape are stated to be spinal column fractures, particularly from T11 to L2, and at C2, C5 and C6. Though cervical fractures were found to be less common than those in the thoracic-lumbar region, they are nonetheless important since they can result in death, or a permanent major disability. With these type of spinal injuries, the need for improved dynamic calibration of manikin test systems is recognized as an essential system development issue.

For newer crashworthy rotary aircraft designed in accordance with MIL-STD-1290, designs include provisions for shielding occupants from injurious loading and occupant/cabin contact in a crash environment. The major mechanisms for such protection include controlled deformation of the airframe structure, stroking of occupant seats, and absorption of impact energy in crush zones. The need to improve and properly evaluate ejection and crashworthy systems, particularly in the dynamic response of the aviator and more specifically for the small aviator, requires improved dynamic calibration systems for the cost effective development of injury criteria data. The continued effort to evaluate ejection and crashworthy systems is needed to improve the overall safety for the aviator in military aircraft.

Numerous injury prediction analyses have been employed to estimate the probability of injury to the head, neck and spinal process. Unfortunately, a lack of standardization has made comparison of results from different laboratories or test programs difficult and sometimes impossible. Information regarding instrumentation location, orientation, and pre- and post-processing of the data is often insufficient to reconstruct the three dimensional time history of occupant response to

a specific acceleration input. In addition, the manikin calibration documentation, when available, only addresses the calibration at the component level and ignores the mechanical response of the complete manikin assembly. The development of improved and complex escape systems and crashworthy seating requires reliable, repeatable, and adequately calibrated manikins that will accurately interact with the escape system to produce realistic seat occupant response, enabling accurate assessment of system performance and associated injury potentials. Repeatability and reproducibility(R&R) are important considerations in the design of a manikin test procedure. Repeatability is referred to as the similarity of results expected to be obtained in repeated testing of a single dummy under identical conditions. Reproducibility is defined as the smallness of variability expected to be obtained between manikins tested under identical conditions. An accurate measure of R&R requires repeated or replicated tests on several manikins so that statistical methods can be applied. Automotive researchers have been able to achieve impressive measures of R&R for whole manikin system response of approximately 4-6% for frontal impacts [Foster, 1977]. The success of the manikins' lateral response R&R was attributed, in part, to the adherence to SAE and CFR Part 572 [CFR, 1994] inspection calibration procedures, and carefully controlled test protocol. Aside from several pendulum tests which are used to provide lateral impacts to the neck, chest, and knees, the remaining CFR Part 572 calibration procedures provide static calibrations of the manikin response along the spinal column. Consequently, it is recognized that these procedures are inadequate to calibrate manikins in multiaxial acceleration environments which are typical of ejections and helicopter crashes. To achieve similar levels of R&R for ejection and crashworthy seating manikin tests, a device must be developed to provide short duration dynamic loadings to calibrate whole manikin response. The device must be capable of providing accurate and repeatable excitations to quantify the relative motion, accelerations, forces, movements and loading at specific anatomical locations (head, occipital condyles, T1, thorax and base of the lumbar spine) and establish a level of confidence in their associated injury mechanisms.

Additional benefit can be realized by enhancing the actuation of the device to replicate a portion of ejection and stroking seat pan accelerations to perform short duration impact, cushion and restraint system studies. The test device will be a cost effective alternative to conventional tower and track testing and, consequently, permit a greater number of tests to be performed. Finally, the resulting data can also be used to refine seat/occupant input in whole body occupant response computer simulation programs such as ATB [Obergefell, 1988] and SOM-LA [Laananen, 1983].

A complete and systematic analysis of the operational requirements, parameters, specifications and design alternatives is accomplished in this program in order to identify and formulate an optimal arrangement for a "Manikin System Test/Calibration Fixture". The optimal conceptual arrangement is selected from a review of potential alternatives. The development of an optimal drive arrangement is accomplished through the analysis and evaluation of several alternatives, with the selection of the optimal drive arrangement being driven primarily by the analytical results of the candidate systems. The final detailed conceptual design is presented in Appendix "A".

2.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the Phase I program effort leading to the detailed conceptual design of a "Manikin System Test/Calibration Fixture" are described in this report.

2.1 Conclusions

The manikin system test and calibration fixture recommended by this report is designed to facilitate the dynamic testing and system-level calibrations of the anthropomorphic vertebral column and head complex of test manikins used in the evaluation of potential injury modes occurring in aircraft ejections and rotary wing mishaps.

An optimal design arrangement for the "Manikin System Test/Calibration Fixture" is selected and documented in this Phase I program. The recommended design arrangement is formulated in accordance with the parameters and specifications defined by a review of the NAWCAD calibration and testing requirements for test manikins. A description and proof of concept for the recommended arrangement is provided in section 8.0 of this report. Detailed conceptual layouts for the overall assembly and for a cross sectional view of the assembled test/calibration unit is present in Appendix "A" of this report.

The detailed conceptual design presented in the design layouts, reference Appendix "A", provides a practical and reliable system for evaluating the systems-level biofidelic performance of test manikins, and improves the predictive consistency of the test manikins under loading conditions encountered in aircraft ejection and crash environments. The fixture is capable of providing controlled, accurate and repeatable excitations sufficient to produce consistent and reliable calibration data. The fixture also meets the requirements, and has the versatility, to provide short duration, dynamic evaluations of aircrew interaction with the various seating and restraint systems for ejection and crash safety.

The design presented in this report is developed to meet the parameters and specifications that were established for the manikin system test/calibration fixture. The design developed in this Phase I program is selected from an extensive number of alternative arrangements. It includes the updated parameters and specifications established in this Phase I effort as presented in Section 5.0 of this report. The final design configuration is selected and defined through an analytical verification of the performance of the design. An optimal design configuration is selected and developed through the formulation and application of the computer simulations presented in Appendix "D" of this report. The final proof-of-concept analysis provided in Section 8.0 of this report establishes the capability and feasibility of the optimal configuration.

2.2 Recommendations

A detailed conceptual design for the manikin system test/calibration fixture has been completed under this project and is presented in the preliminary design layouts presented in Appendix "A" of this report. The design is developed to meet the parameters and specifications that are required for the calibration and testing of manikin systems. Fabrication of the test/calibration fixture is

needed in order to meet the manikin system test requirements and to provide a means for the calibration of the manikin data collection systems utilized in the evaluation of aircraft ejection systems and crash safety equipment. This fixture is required to evaluate and improve the predictive consistency of the systems-level biofidelic performance of a test manikin under load conditions encountered in aircraft ejection and crash environments.

It is recommended that the manikin system test/calibration fixture be fabricated in accordance with the detailed conceptual design provided by this report.

3.0 PHASE I DEVELOPMENT

This report documents the results obtained under Naval Air Warfare Center Aircraft Division contract N62269-96-C-0028, entitled "Manikin Test and Calibration System".

3.1 Purpose and Scope of the Research Effort

The technical objective of this program is to provide the technical support, as required by NAWCAD, in the areas related to research, detailed conceptual design or prototype design of a test/calibration fixture for the dynamic testing and calibration of manikin systems. This fixture is required to evaluate and improve the predictive consistency of the systems-level biofidelic performance of a test manikin under load conditions encountered in aircraft ejection and crash environments. The fixture must be capable of providing controlled, accurate and repeatable excitations sufficient to produce consistent and reliable calibrations. Additionally, the fixture must possess the versatility to conduct short duration, dynamic studies of aircrew interaction with various seating and restraint systems designed for ejection or crash conditions.

3.2 Results of Individual Tasks

The technical objectives of the Phase I program was undertaken in the form of a multi-task program. The results of the individual tasks are presented below.

1. Define Parameters and Specifications.

System parameters and specifications that need to be satisfied by the embodiment of the manikin system test/calibration fixture were identified and limits and/or values were established. An operational analysis, reference section 4.0 of this report, was accomplished in order to identify system parameters and requirements. The facilities and operational requirements were reviewed by Conrad Technologies, Inc. (CTI) in order to establish acceptable physical envelopes for the test and calibration fixture. The various requirements were also presented and reviewed in a meeting at NAWCAD. Testing/calibration limits, environmental parameters and target cost limits were also reviewed. The final definitive parameters and specifications selected for the manikin system test and calibration fixture are presented in Section 5.0 of this report.

2. Selection of Candidate Design Alternatives

Candidate design alternatives were identified and are presented in this report. The various approaches to the development of design alternatives include the review of design trade-offs with consideration given to power source, type of drive, materials of construction, instrumentation, control strategies, method of mounting, manufacturing cost, sensitivity, reliability and accuracy. Design alternatives were selected based on the objective of maximizing the potential for satisfying the requirements and specifications of the manikin system test/calibration fixture. Descriptions of the various concepts, with special emphasis on the drive system components that serve to meet acceleration requirements, is presented in section 6.0 of this report.

3. Analytical Formulation and Development

Analytical procedures were formulated to evaluate and determine the engineering estimates of power, size, control, performance and related factors for each of the manikin system test/calibration concepts. The analytical results were used in the redefining and development of the potential alternatives. Analytical procedures and results are presented in Appendix "E " of this report.

4. Final Selection, Verification, and Proof-of-Concept

Based on the results of the performance analysis of the various concepts, and a review of the design features and trade-offs related to the development of an optimal arrangement, a final conceptual design was selected. Factors considered in the development and selection of the final concept included operating efficiency, weight, cost, environmental effects, materials, manufacturing cost and logistic support. Preliminary design layouts of the selected optimal system were then completed. A final proof-of-concept analysis was accomplished in order to provide a definitive evaluation of the capability and feasibility of the optimal configuration.

4.0 OPERATIONAL ANALYSIS

The manikin test/calibration fixture developed under this program is designed to facilitate the dynamic testing and system-level calibrations of the anthropomorphic vertebral column and head complex of test manikins used in the evaluation of potential injury modes for aircraft ejection and rotary wing mishaps.

It has the dual objective of providing a reliable excitation pulse for calibration of the manikin instrumentation and also possess the versatility to conduct short duration, dynamic studies of aircrew interaction with various seating and restraint systems designed for ejection or crash conditions. The test/calibration fixture needs to be sized and developed to produce an accurate manikin assembly excitation pulse for calibration of the manikin instrumentation and also be able to simulate an adequate portion of seat pan acceleration signatures consistent with ejection and crash environments. An analysis of the operational parameters for both calibration and simulation

of ejection and crash environments was accomplished and is presented here in order to identify the operational parameters and specifications for the system.

Operational parameters and specifications were evaluated and defined by CTI. To accomplish this, CTI utilized its prior experience in the development of manikin equipment for ejection and automotive crash studies, computer simulation of aircrew ejections and energy absorbing crashworthy seats, and work in the development of various other aircrew safety-related systems. Specifically, a thorough review of available biomechanics literature, analytical computer simulation programs (ATB [Obergefell, 1988] and SOM-LA [Laananen, 1983]), and CTI's in-house documents was conducted to formulate the operational information necessary for the development of a system that will meet the overall technical objectives of the test/calibration fixture.

3.1 Manikin Calibration

The seat occupant's anthropometry, initial positioning, center of gravity, seat/restraint geometry, and flight gear are all factors which influence response of the manikin, or the seat occupant, when forces are applied to seat. Researchers have shown that improper positioning of the seat occupant or manikin, leading to variations in the location of the seat occupant's center of gravity can substantially influence the response and injury modes of the seat occupant. Accordingly, it is recognized that the calibration of manikins for the purpose of establishing controlled, accurate and repeatable results must include the complete, dressed manikin and the associated seat/restraint system. The design of the manikin calibration fixture must be properly sized and provide for consistent adaptation and control of the manikin response envelope.

The evaluation of ejection and crashworthy seating systems has traditionally been based on track and tower tests which utilize highly-instrumented, biofidelic manikins as human surrogates. Figure 1 presents an overall layout and sensor arrangement for the Hybrid III biofidelic manikin. The common sensor arrangement for ejection and crashworthy seating tests includes six degree-of-freedom (6DOF) loadcells in the upper neck, lower neck, thoracic, and lumbar regions, and various triaxial arrangements of accelerometers in the head and thorax.

The data generated in these tests is correlated to experimental human test or cadaver data in an attempt to assess injury mechanisms and potentials, and as a validation criteria of manikin biodynamic response. For example, the Navy currently uses multiaxial load/duration limits in lumbar and cervical spinal processes to determine the risk of injury. Figures 2A and 2B present the compression limits for the lumbar and cervical spinal regions, respectively. Similarly, multiaxial acceleration data is also used to assess the risk of injury. Some of the analyses which utilize this data include the Eiband Criteria [Eiband, 1959] and the Multiaxial Dynamic Response Criteria (MDRC) [Brinkley, 1989].

Current manikin calibration documentation, when available, only addresses the calibration at the component level and ignores the mechanical response of the complete manikin assembly. Aside from several pendulum tests which are used to provide lateral impacts to the neck, chest, and knees, the remaining CFR Part 572 calibration procedures provide static calibrations of the

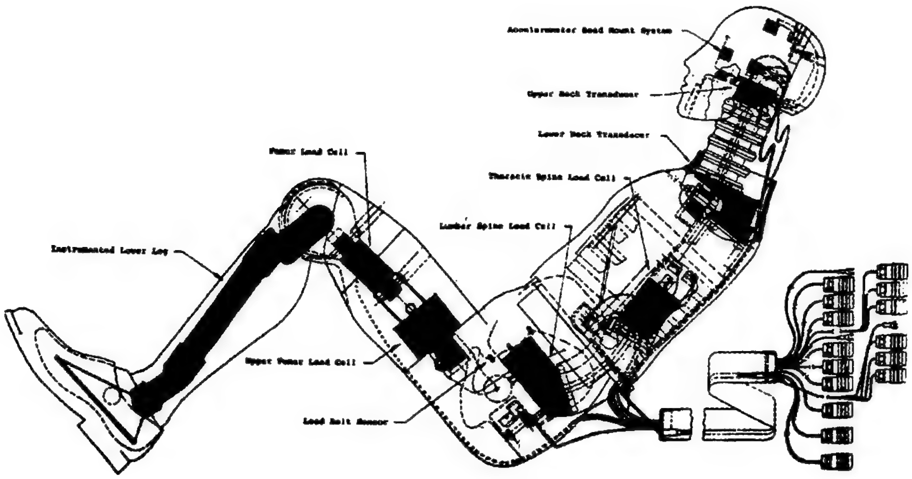
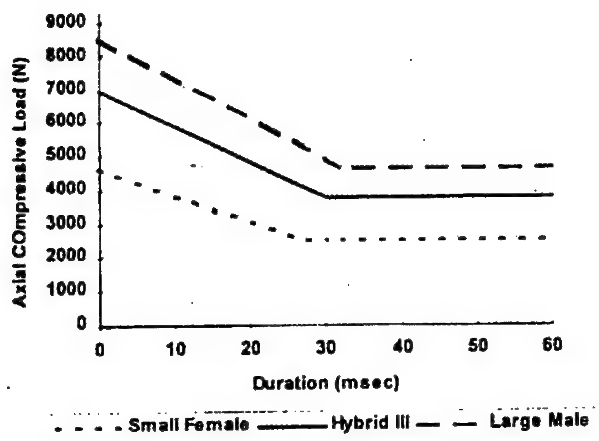
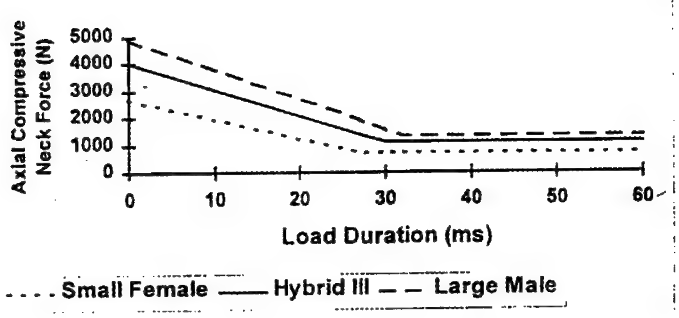


Figure 1. Overall Layout of the Hybrid III Manikin [Denton, 1987]



Lumbar



Neck

Figures 2A & 2B. Lumbar & Neck Compressive Load/Duration Limits [Melvin, 1985]

manikin response along the spinal column. While these types of calibrations have produced impressive measures of Repeatability and reproducibility (R&R) for frontal impact automotive testing (4-6% [Foster, 1977]), it is apparent that these procedures are inadequate to calibrate manikins in multiaxial acceleration environments which are typical of ejections and helicopter crashes. To achieve similar levels of R&R for ejection and crashworthy seating manikin tests, the calibration device must be capable of providing short duration dynamic loadings to calibrate whole manikin response.

To provide seat/manikin calibrations a well-defined, and repeatable seat pan acceleration excitation must be established which is capable of inducing a reasonable manikin response without producing permanent changes in the assembled manikin's dynamic response characteristics. For example, referring to Figure 1, the flexure in the manikin neck and lumbar assemblies are obtained from elastomeric assemblies which are preloaded through an interior cable. Adjustments to the cable tension will change the stiffness properties of the assemblies. While SAE/CFR Part 572 specifies a series of component static and pendulum tests and corresponding response corridors to verify their behavior it is not desirable to disassemble the manikin after each impact test to perform these calibrations. More importantly, these types of calibrations do not produce reliable measures of whole manikin response.

The seat occupant's anthropometry, initial positioning, center of gravity, seat/restraint geometry, and flight gear are factors that influence the motion and response of the manikin or the seat occupant to the application of forces or acceleration on the seat. Researchers have shown that inadequate control of the seat occupant's, or manikin's, position in the seat, resulting in variations in the location of the seat occupant's center of gravity, can substantially influence the response and injury modes of the seat occupant. Accordingly, it is recognized that the calibration of manikins for the purpose of establishing controlled, accurate and repeatable results must include the complete, dressed manikin and the associated seat/restraint system. The design of the manikin calibration fixture must be properly sized and provide for consistent adaptation and control of the manikin response envelope.

To obtain accurate calibrations, the frequency and amplitude of the applied forces must be carefully chosen to excite the desired transducers (those which are critical to injury prediction) while limiting the manikin's component load levels to safe values. In addition, the orientation of the calibration pulse must be consistent with the anticipated direction(s) of manikin acceleration during testing. For example, to calibrate the whole manikin response for a manikin that will be used to predict injuries that may result from catapult accelerations (Gz), the orientation of the calibration pulse must be collinear (or within some corridor) with the axis of the anticipated seat/catapult configuration. Moreover, referring to the analyses shown in Figures 2A & 2B, the calibration pulse must produce measurable signal levels in both the neck and lumbar transducers while maintaining the lumbar preload adjustment.

The whole-manikin response can be maximized by applying a calibration pulse whose frequency content is at, or near, the natural frequencies of the manikin. Unfortunately, for the sitting manikin, the natural frequencies for Gz response is dependent upon the manikin size and

configuration, and has not been extensively quantified. However, numerous researchers have experimentally measured natural frequency and damping of sitting humans using impact-response techniques. Consequently, recognizing that current biofidelic manikins are designed to approximate the response of humans, those data which characterize the human dynamic response will be used for this study. Brinkley, for example, estimates the vertical natural frequency to be 8.4 Hz [Brinkley, 1989]. Figure 3 presents Merten's research, which demonstrate that the natural frequency increases slightly with the mean Gz acceleration level [Merten, 1978]. Finally, according to the specifications for the ADAM spinal design (ISO-5982-1981), based on human studies, the impedance characteristics for the midsize manikin should be such that:

> "The normal gravity (0.5 Gz vibration acceleration amplitude) driving point impedance modulus of the seated 50th percentile manikin, in the 0 to 30 Hz frequency domain, should be such that a major peak of 4000 (1.0+/-0.10) Nsec/m occurs at frequency of 5 (1+/-0.10) Hz, a lesser peak of 2500 (1.0+/-0.10) Nsec/m occurs at a frequency of 10 (1.0+/-0.10) Hz and should reflect an overall damping ratio of 0.30 (1.0+/-0.10)."

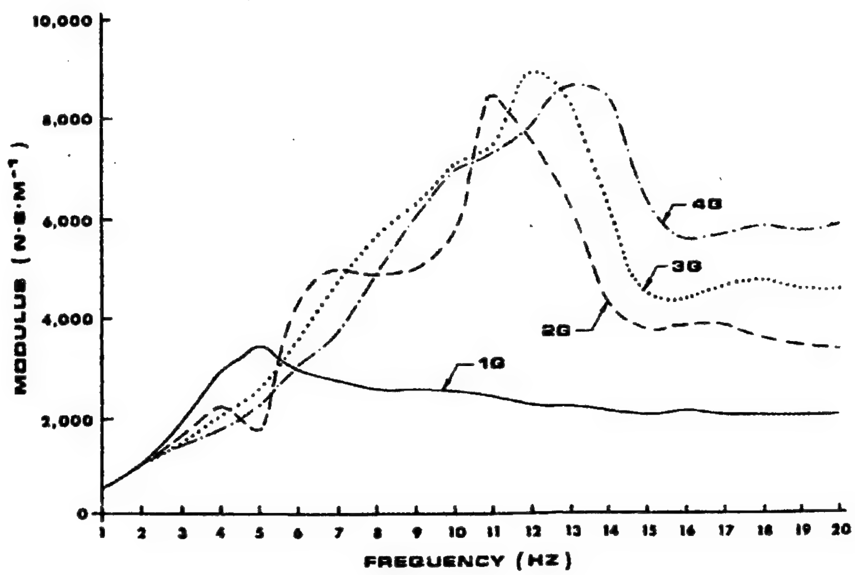
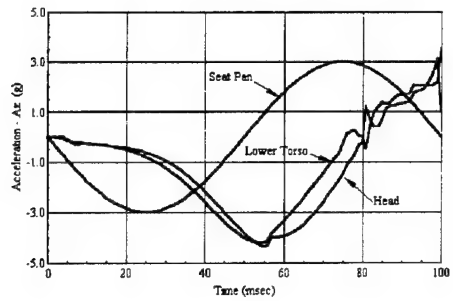


Figure 3. Impedance of the Upright Sitting Human at Various Mean Accelerations [Merten,1978]

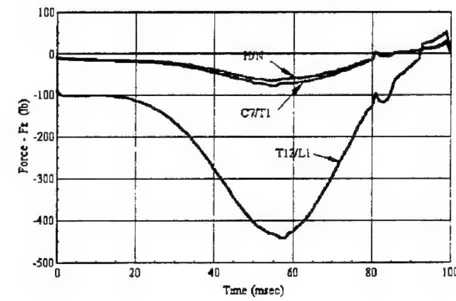
With all of these data in mind, it is clear that the vertical natural frequency of the sitting human spinal column resides between 5 - 14 Hz. Similar studies of seated humans exposed to frontal and side accelerations have yielded comparable natural frequencies of about 10 Hz. For the purposes of establishing a baseline calibration pulse, the available research indicates that an excitation frequency of 10 Hz will provide acceptable multiaxial calibrations. In addition, consistent with human acceleration testing, a sinusoidal calibration acceleration signature is deemed to be desirable, and is recommended.

To determine the optimal acceleration amplitude, several calibration signatures of increasing peak amplitude were synthesized. The manikin response for each candidate pulse was simulated using a previously-validated, sitting, 50th percentile ATB manikin model. The candidate pulses were

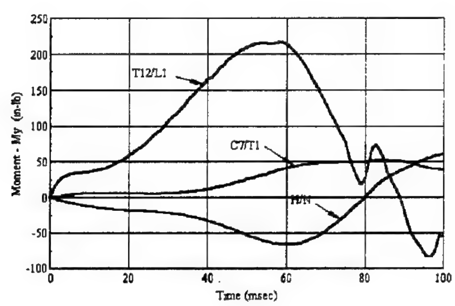
applied to the seat pan in the vertical (Z) and fore-aft (X) directions. Simply stated, an acceptable calibration amplitude was identified when measurable transducer output was computed at the T12/L1, C7/T1, and Head Neck (H/N) junctions. The optimal peak calibration acceleration amplitude was found to be 3 g. The simulated occupant response for this vertical calibration pulse is presented in Figures 4A-4D.



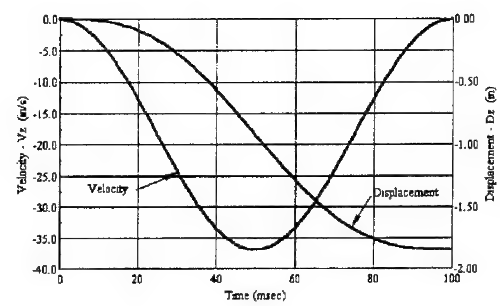
4A - Segment Accelerations



4B - Joint Forces



4C - Joint Moments



4D - Platform Motion

Figures 4A - 4D Calibration Pulse Simulation Results

Referring to Figure 4A, the computed lower torso and head segment response indicates that there is an amplification of the calibration acceleration of approximately 1 g (30 %). It is also important to note that measurable manikin interaction with the restraint system is apparent around 80 milliseconds. Figures 4B and 4C present the simulated joint forces at the T12/L1, C7/T1, and H/N junctions, respectively. The T12/L1, C7/T1, and H/N joints all experience compressive loads. The maximum forces for each of these joints are approximately -450 , -70, and -60 lb, respectively. The maximum moments for these joints are approximately 230, 50, and -70 in-lb, respectively. Unlike, the computed axial forces, there is a change of sign between the C7/T1 and H/N moments. The sign of these moments is determined by the relative positioning of the head and neck segment centers of gravity. For this simulation the head was initially positioned such that the aft portion of the head contact ellipse was tangent to the seat back plane. The resulting configuration produced an alignment in which the head/helmet c.g. was positioned forward of the head pivot (H/N joint) but behind the neck pivot (C7/T1 joint). Figure 4D presents the platform

velocity and displacement. For the 3 g sine wave calibration pulse of 100 ms duration, the maximum platform velocity and displacement is 37 in/sec and 1.8 in, respectively. For a 3 g half-sine calibration pulse of 100 ms duration, the maximum platform velocity is 74 in/sec with maximum displacement dependent on braking and recovery of the test. The simulation of the fore-aft (X) calibration pulse produced a manikin response which was similar in magnitude.

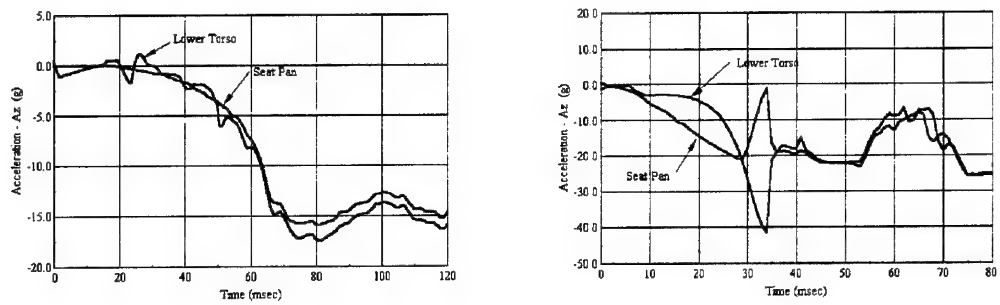
Short Duration Manikin Testing

The contemplated manikin test and calibration device is intended to provide limited ejection and crashworthy seat testing. Recognizing that this device is not intended to completely replace existing track and tower testing, a determination of the maximum feasible duration of seat pan acceleration profile to be replicated must be made to size the device. To maximize its utility, CTI determined that the test device must be capable of producing seat pan accelerations of sufficient duration to permit the predictions of injury to the T12/L1, C7/T1, and H/N body regions to be made using current techniques such as the MDRC [Brinkley, 1989]., Eiband Criteria [Eiband, 1959], and various load/duration limits [Melvin, 1985]. The underlying mechanism behind all of the current injury prediction techniques is that injurious levels of strain build up in various body regions over period of time (approximately 50-150 milliseconds) when the body is exposed to large accelerations whose dominant frequency is at, or near, the natural frequencies of the human body. Consequently, CTI determined that a survey of manikin response data from ejection and crashworthy seat tests to locate the maximum forces in critical regions of the body would serve to bound the requisite duration of the replicated seat pan acceleration profiles.

To establish the short duration manikin test requirements, typical ATB-simulated seat pan signatures and the associated vertical manikin response from ejection and crashworthy seats were analyzed, reference ejection data in Appendix "B" and crashworthy seat data in Appendix "C". Specifically, similar to the calibration pulse analyses, accelerations in the lower torso and Head and forces and moments in T12/L1, C7/T1, and H/N regions were used as representative measures of manikin response. Figure 5A presents the vertical seat pan and manikin lower torso accelerations for the catapult phase of a ejection tower test. Similarly, Figure 5B presents the vertical seat pan and manikin lower torso accelerations for a crashworthy seat vertical drop test. In both tests the primary impact (or bottoming out) of the manikin buttocks with the rigid seat pan occurs between 30-40 milliseconds. It is worth noting that while the seat pan acceleration for the ejection appears to be unaffected by contact with the manikin, there is a pronounced rebounding of the crashworthy seat pan which coincides with the impact event. In addition, unlike the ejection seat, the crashworthy seat acceleration signatures demonstrate that a considerable differential velocity develops between the seat pan and the lower torso prior to mutual contact. However, in both tests, the acceleration response of the lower torso oscillates around the seat pan acceleration after the initial lower torso/seat pan contact

Figures 6A and 6B present corresponding force and moment data for the ejection and stroking seat simulations, respectively. In both tests, maximum values for the T12/L1, C7/T1, and H/N compressive forces (-Fz) are contained within the first 120 milliseconds of the simulated event (approximately 120 milliseconds for the ejection and 80 milliseconds for the drop test). The ejection seat produces steadily increasing compressive loads which reach their maximums around

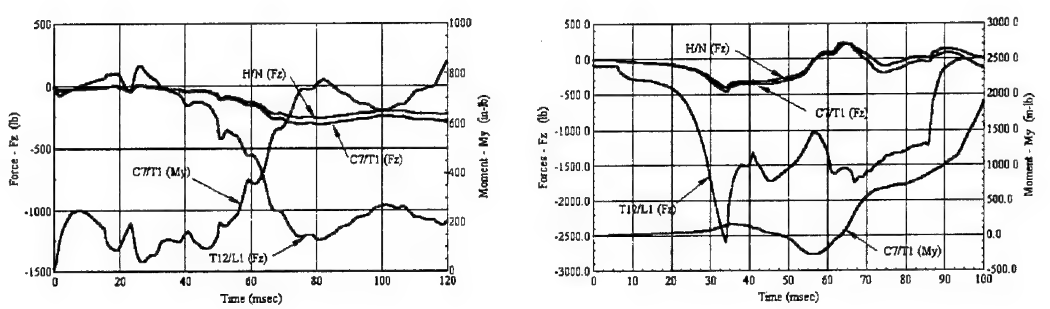
80 milliseconds and are sustained until at least 120 milliseconds. Alternatively, the characteristically high crashworthy seat onset rates which result from the rapid deceleration of the lower torso during initial lower torso/seat pan contact produce short duration compressive loads with maximums at about 35 milliseconds.



5A - Ejection Seat

5B - Crashworthy Seat

Figures 5A & 5B Seat Pan and Lower Torso Accelerations



6A - Ejection Seat

6B - Crashworthy Seat

Figures 6A & 6B T12/L1, C7/T1, H/N Forces and Moments

In both tests the moment associated with neck flexion (+My) builds up over an extended period of time (>150 milliseconds). Preliminary analyses have determined that to replicate the seat pan accelerations until such time as the maximum neck flexion occurs would result in excessively large actuation requirements that are not consistent with the intended use of the device. Consequently, it is recognized that full-scale track and/or tower testing would still be required to assess injuries related to maximum neck moments. Accordingly, based on its ATB analyses, CTI has determined that a device which can replicate ejection and crashworthy seat pan accelerations for 80 and 25 milliseconds, respectively, should be adequate for assessing injuries to most body regions.

With 80 milliseconds of ejection simulation, the maximum velocity and acceleration requirements are 151.9 in/sec and 17.16 g's respectively, reference Appendix "B". The maximum velocity and

acceleration requirements for 25 milliseconds of crashworthy simulation are 57.96 in/sec and 20.0 g's respectively, reference Appendix "C". The maximum displacement is 2.23 inches for ejection simulation and 0.2898 inches for crashworthy seating.

To determine the requisite frequency response of the manikin test device, the ejection and crashworthy seat pan accelerations were digitally filtered (low pass) at two frequencies. Cutoff frequencies of 25 and 50 Hz were chosen as realistic response limits for the device. Figures 7 and 8 present the filtered data. In both tests, the filtered data demonstrate that the seat pan acceleration signatures can adequately be replicated with a device whose maximum frequency response is 50 Hz. For the crashworthy seat there is a noticeable degradation in the replicated acceleration signature when the maximum frequency of the device is reduced to 25 Hz. Consequently, it is recommended that the contemplated manikin test device be capable of providing a maximum frequency response between 25 and 50 Hz.

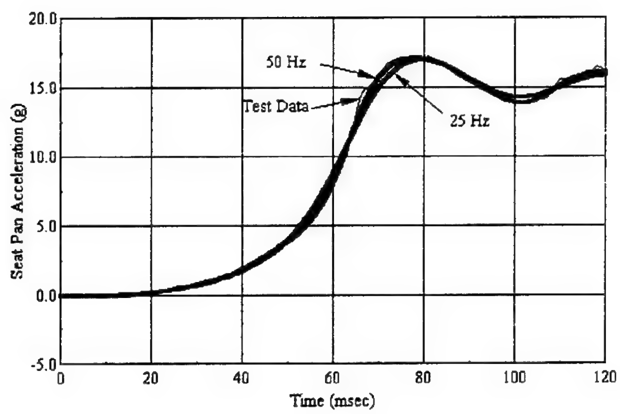


Figure 7. Ejection Seat Acceleration Filtered at 25 and 50 Hz

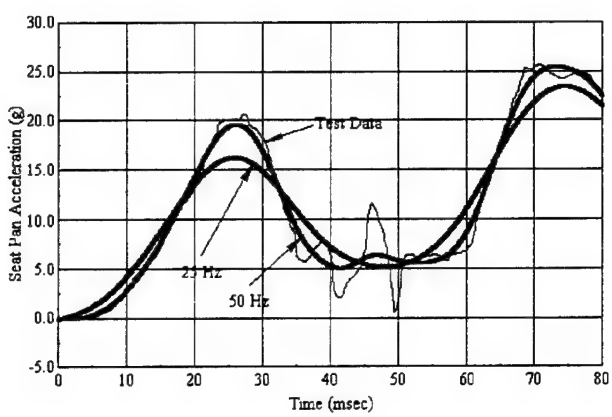


Figure 8. Crashworthy Seat Acceleration Filtered at 25 and 50 Hz

5.0 PARAMETERS AND SPECIFICATIONS

The overall physical response characteristics of the seat-occupant, or of the instrumented manikin system serving as the surrogate seat-occupant during ejection and crashworthy seat testing, serves to define some of the parameters and the criteria for the manikin system test/calibration fixture. Analysis of the physical and mechanical response characteristics of the instrumented manikin system, a review of test data requirements and a review of the literature related to the performance of the instrumented manikins that are used in the evaluation of injury potential during ejection from an aircraft and helicopter mishaps provide the basis for establishing the parameters and specifications for the development of the manikin system test/calibration fixture.

System parameters and requirements are identified by the operational analysis presented in this report. Parameters and specifications that need to be satisfied by the embodiment of the manikin system test/calibration fixture are identified and limits and/or values are established in this report. The facilities and operational requirements were reviewed by Conrad Technologies, Inc. (CTI) in order to establish acceptable physical envelopes for the test and calibration fixture. Testing/calibration limits, environmental parameters and target cost limits also establish some parameters or design considerations.

Final selection of the testing and calibration performance limits for the system is determined from the operational information. The final set of parameters and specifications for development of manikin test/calibration fixture are presented here.

1) Maximum total test platform load is specified at 400 lbs. The 400 lb load may consist of any combination of manikin, equipment, seat, fixture assembly hardware or other equipment not to exceed a total of 400 lbs. The 400 lb maximum platform load, identified as potentially allowing for a 245 lb manikin, a 100 lb seat with seat equipment and with 55 lbs allowed for fixture assembly hardware, was defined by NAWCAD personnel at February 6, 1996 meeting.

2) The test platform is to provide one axis of linear motion with the vector orientation of this axis being at 90 degrees from the horizontal.

3) Maximum acceleration requirement for the test platform is specified at 20 g's.

4) Acceleration onset rate for the driving acceleration is specified at 1000g/sec.

5) Maximum inertial moment on test platform is specified as 400 lbs at 30 inches above test platform.

6) Maximum velocity requirement for the test platform is specified at 152 inches/second.

7) Maximum total displacement for the test cycle displacement including braking and recovery is specified at 14 inches.

8) The maximum driving frequency required for the test platform is specified at 30 Hz.

9) Based on the operational analysis in Section 4.0, the maximum acceleration for manikin system calibration is specified at 3g's.

10) The test platform is required to have the capability of being programmed to produce a full sine wave acceleration loading pattern with 3g peak acceleration for calibration of manikin systems with a consistent and repeatable acceleration loading pattern.

11) The test platform is required to have the capability of being programmed to provide acceleration onset and acceleration loading conditions for simulation of the initial 80 ms of ejection sequence as shown in Figure 7 of the operational analysis.

12) The test platform is required to have the capability of being programmed to provide acceleration onset and acceleration loading conditions for simulation of the initial 25 ms of an ejection sequence as shown in Figure 8 of the operational analysis.

13) The overall size of the unit is to be generally in accordance with the size presented in the proposal and illustrated in Figure 9 of this report. The unit is to be fully operable within a test laboratory having a ceiling height of 17 feet.

14) The motion of the test platform is to be programmable and allow preselection of the desired acceleration profile within the specified limits of displacement, velocity, acceleration, acceleration onset and driving frequency specified above.

6.0 CANDIDATE DESIGN ALTERNATIVES

6.1 Selection of Candidate Design Alternatives

The candidate design alternatives selected for evaluation in this Phase I program include the concepts presented in the proposal and include candidate design alternatives that are identified through a research of alternative drive components and alternative system control techniques. Alternatives which have potential to meet the requirements of the manikin system test/calibration fixture, are also developed from a review of alternative power sources and a review of commercial equipment options. Candidate design alternatives are generated based on the parameters and requirements identified in Section 5.0 above for the manikin test/calibration fixture.

The selection of candidate concepts for the manikin test/calibration fixture is based on an evaluation of the parameters and specifications for the system and on research effort directed at the identification of the possible design approaches that might satisfy these parameters and specifications. Design trade-offs are incorporated into the development of the individual concepts in order to obtain conceptual arrangements that will best meet the requirements for the manikin test/calibration fixture. Design trade-offs and design alternatives are evaluated and trade-offs

selected for maximizing the potential of satisfying the specifications and requirements of the manikin system test/calibration fixture.

Three alternative concepts for the manikin system were presented as concept #1, concept #2 and concept #3 in the Phase I proposal. The concepts were identified in the proposal as having potential for satisfying the overall system requirements. These concepts serve as the basic design reference for the development of the manikin system test/calibration fixture and are selected in the Phase I effort for further analysis and development.

The concepts selected as candidate concepts for this application are identified below.

Concept # 1, shown in Figure 9, is a pneumatically driven and hydraulically servo controlled acceleration platform. See section 6.2 below for further description.

Concept # 2, shown in Figure 10, is a compressed air over hydraulic drive system with a computer programmed electro-hydraulic servo system utilized for closed loop control of the acceleration platform. See section 6.3 below for further description.

Concept #3, shown in Figure 11A and 11B, is a compressed air over hydraulic drive system with a computer programmed electro-hydraulic servo system utilized for closed loop control of the acceleration platform and with adjustable orientation of the acceleration vector. See section 6.4 below for further description.

Concept #4, shown in Figure 12, incorporates a compressed gas drive system that is preset to reproduce the required acceleration profiles. The overall arrangement of concept #4 is similar to concept #1 with the exception that concept #4 utilizes a compressed gas drive system that is preset for the desired acceleration profile and does not require any electro-hydraulic servo valves. See section 6.5 below for further description.

Concept #5, shown in Figure 13, incorporates a compressed gas drive system that is preset to reproduce the required acceleration profiles. The overall arrangement of concept #5 is similar to concept #2 with the exception that concept #5 utilizes a compressed gas drive system that is preset for the desired acceleration profile and does not require any electro-hydraulic servo valves. See section 6.6 below for further description.

Concept #6, shown in Figure 14A and 14B, incorporates a compressed gas drive system that is preset to reproduce the required acceleration profiles. The overall arrangement of concept #6 is similar to concepts #3 with the exception that concept #6 utilizes a compressed gas drive system that is preset for the desired acceleration profile and does not require any electro-hydraulic servo valves. See section 6.7 below for further description.

Concept #7, shown in Figure 15, utilizes a large mass, as a counterbalancing and driving mass, with an appropriate mechanical leverage system in order to provide constant acceleration of a manikin system over a limited range of motion or time. The overall arrangement of concept #7 is

similar to concept #1 with the exception that concept #7 utilizes a mechanical lever and large mass as the drive system. See section 6.8 below for further description.

Concept #8, shown in Figure 16, utilizes a number of compression springs as the drive system to provide acceleration of a manikin system over a limited range of motion. The overall arrangement of concept #8 is similar to concept #1 with the exception that concept #8 utilizes compression springs as the drive system. See section 6.9 below for further description.

The above eight concepts are described in greater detail below. In addition, analytical procedures are formulated for the various conceptual arrangements and are utilized in the development of the concepts. The analytical procedures are formulated to provide a means of determining engineering estimates of performance and size of system components. The estimates of size are incorporated into the design layouts in order to establish the optimal configuration for a given concept. Design trade-offs are reviewed in the analysis and, if appropriate, are incorporated into the development of the design of the individual concepts. The analytical process serves to define the design and performance parameters for a given conceptual arrangement and allows for the selection and development of design parameters that will maximize the performance and potential for satisfying the system requirements. This serves to develop conceptual arrangements that will best meet the requirements for the manikin system test/calibration fixture.

Each potential system concept is developed with sufficient detail such that the characteristics and performance of that concept can be analyzed and definitively evaluated. Each system concept includes the selection of subsystem alternatives within the candidate concept such as power source, type of drive, materials of construction, instrumentation, control strategies, method of mounting, and any related feature that might influence the performance or configuration of the concept in any significant manner. Sizing of the system components, such as the area of the pneumatic and hydraulic cylinders, charging pressure, charging volume, and sizing of the overall system is dependent upon the system requirements as well as the overall estimated efficiency of the system.

6.2 Concept #1: Pneumatically Driven, Hydraulically Controlled, Coaxial Drive, Acceleration Platform

6.2.1 Description of Concept #1

An acceleration platform, with required system components, is illustrated in Figure 9. In this arrangement, acceleration is provided in the vertical direction. The manikin and seat is shown as being mounted on the acceleration platform in the upright position but can be mounted in any desired test position. The acceleration force is provided by a pneumatic cylinder with the power for a test cycle provided by compressed air from a pressurized charge chamber. The system is configured with the drive cylinder and bearing support located approximately coaxial with the mass reaction force. Motion control and guidance of the acceleration platform, including control

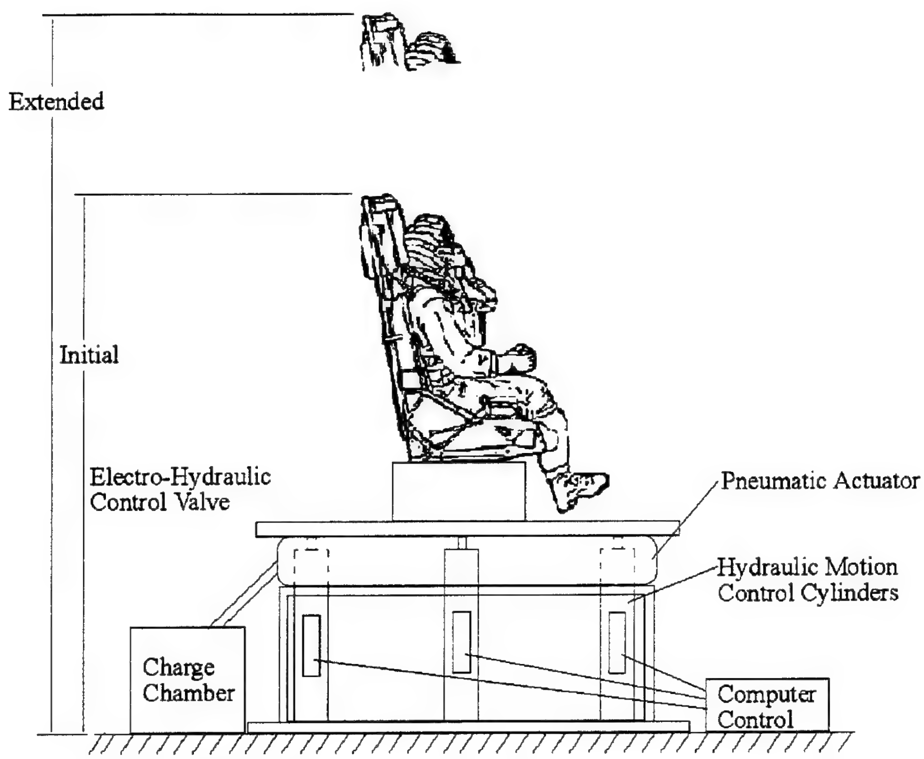


Figure 9 Pneumatically Driven, Hydraulically Controlled, Coaxial Drive

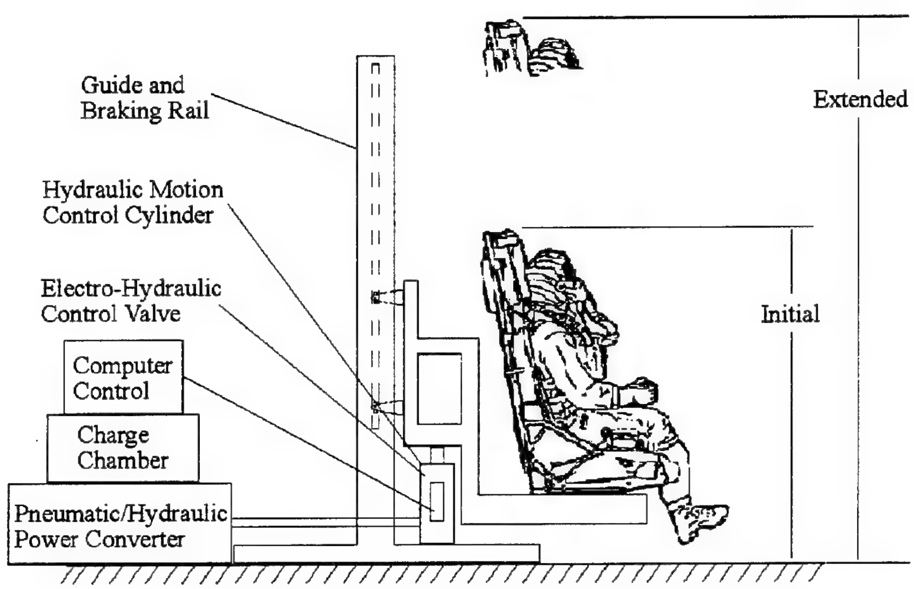


Figure 10 Air Over Hydraulic, Hydraulically Controlled, Off-Center Drive

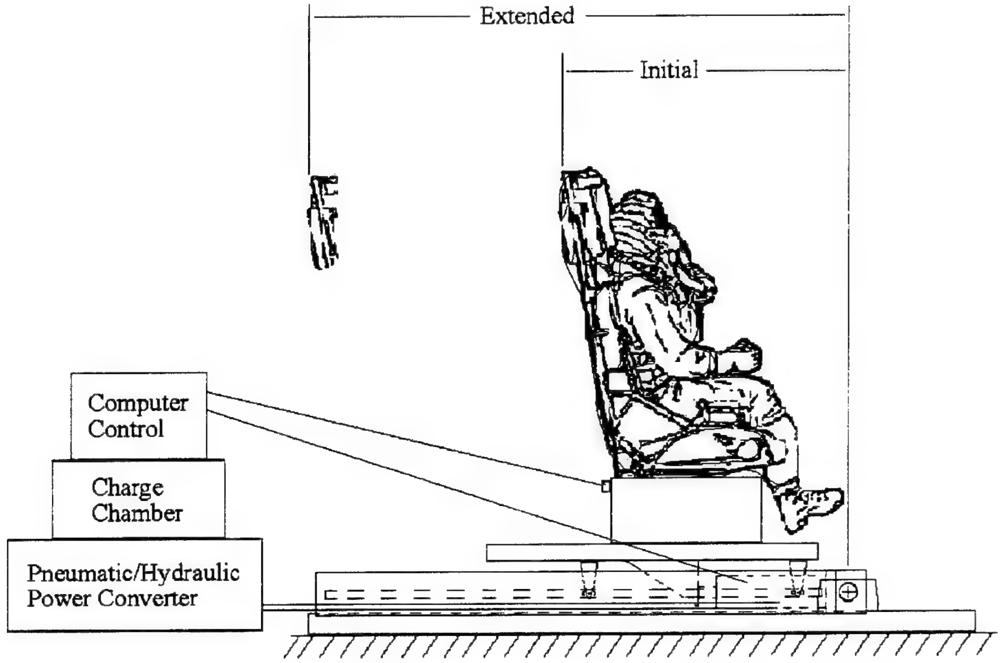


Figure 11A Air Over Hydraulic, Hydraulically Controlled Off-Center Drive With Adjustable Acceleration Vector (Sled Mode)

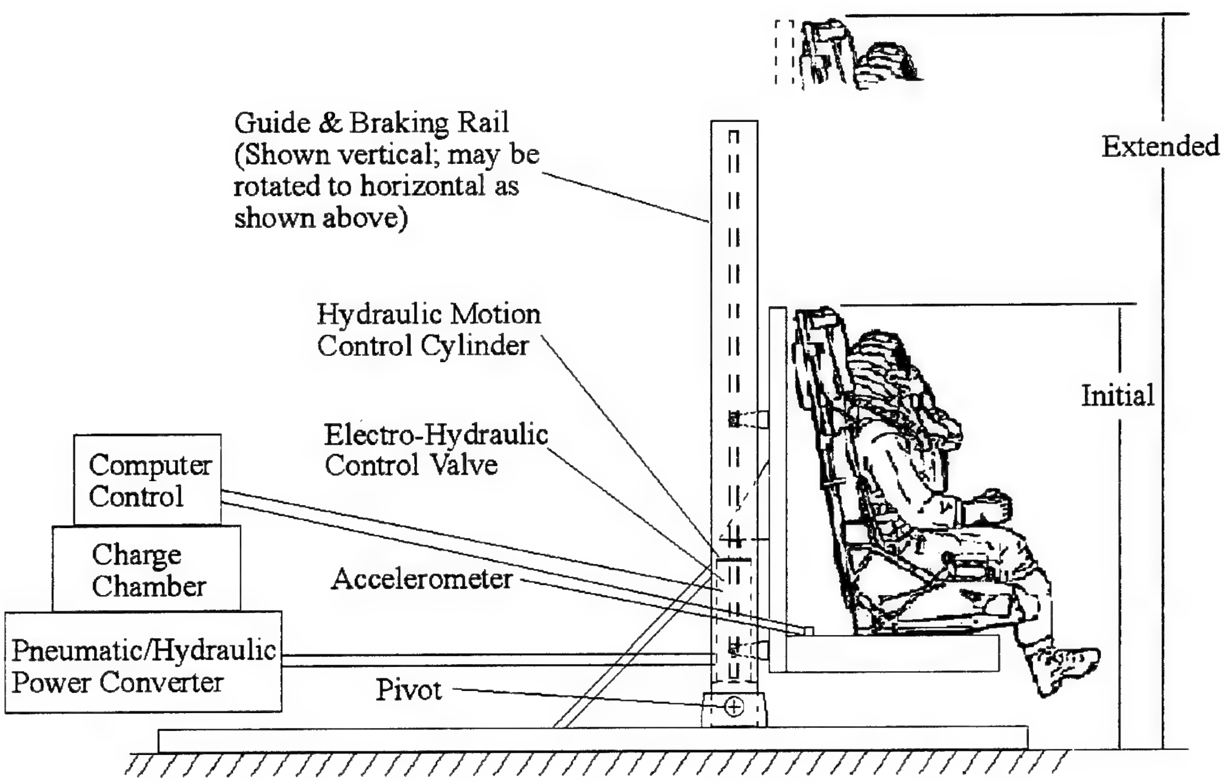


Figure 11B Air Over Hydraulic, Hydraulically Controlled Off-Center Drive With Adjustable Acceleration Vector (Tower Mode)

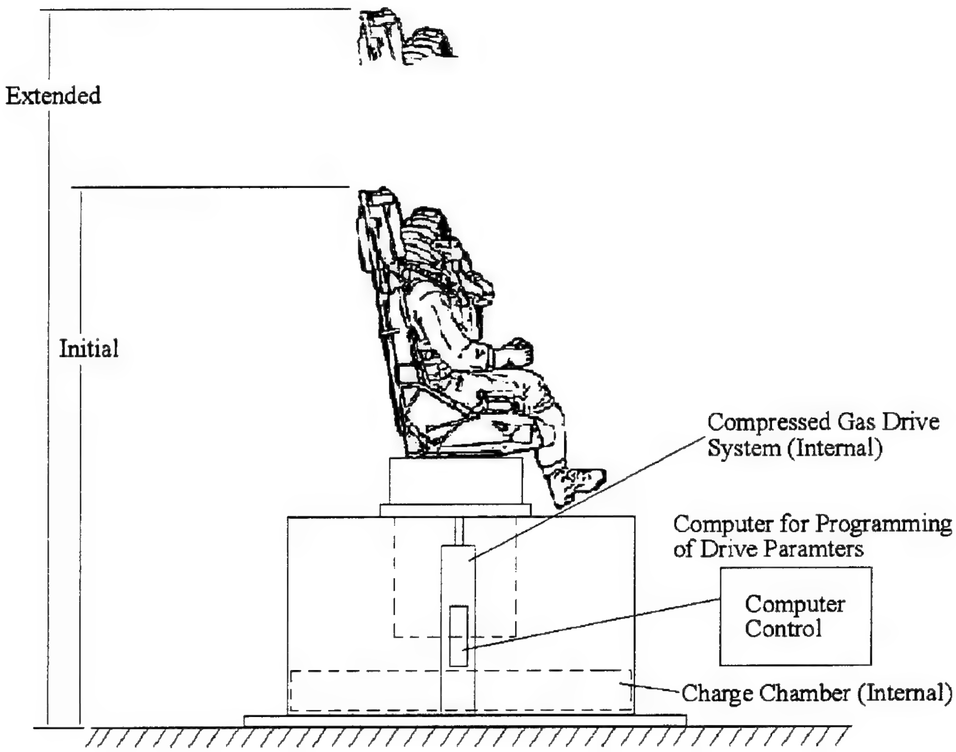


Figure 12 Computer Programmed, Compressed Gas, Coaxial Drive, Vertical Motion Acceleration Platform

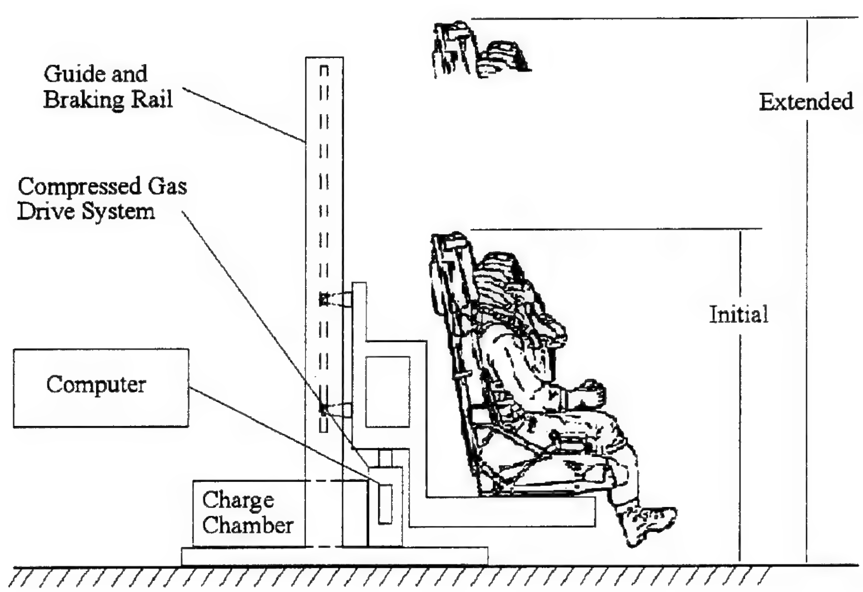


Figure 13 Computer Programmed, Compressed Gas, Off-Center Drive, Vertical Motion Acceleration Platform

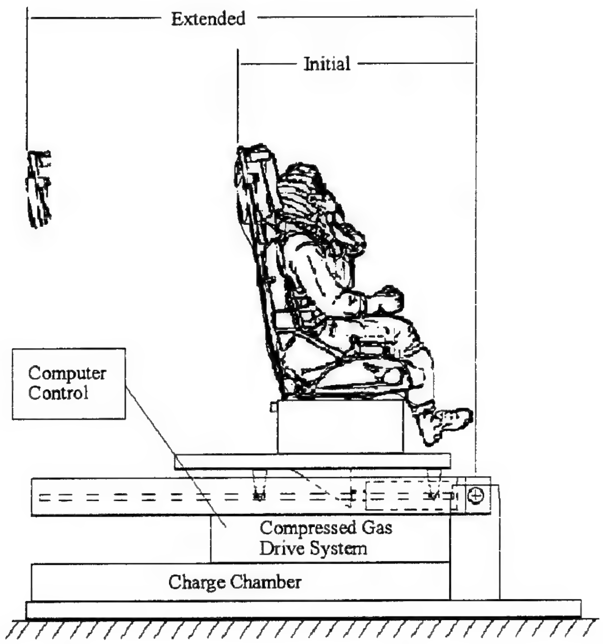


Figure 14A Computer Programmed, Compressed Gas, Off-Center Drive With Adjustable Acceleration Vector (Horizontal Mode)

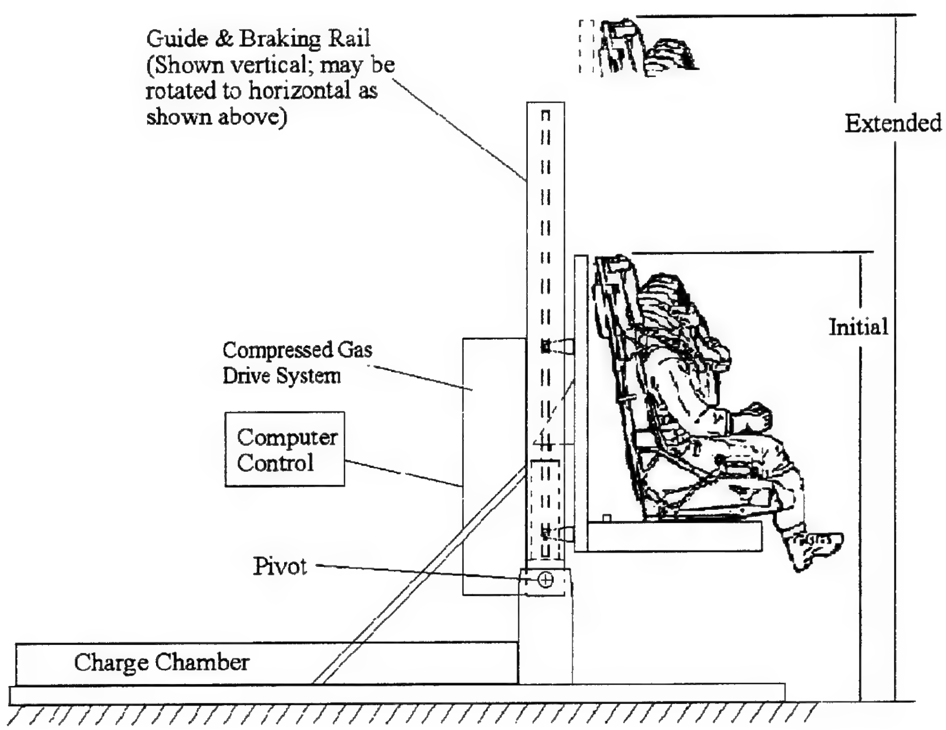


Figure 14B Computer Programmed, Compressed Gas, Off-Center Drive With Adjustable Acceleration Vector (Tower Mode)

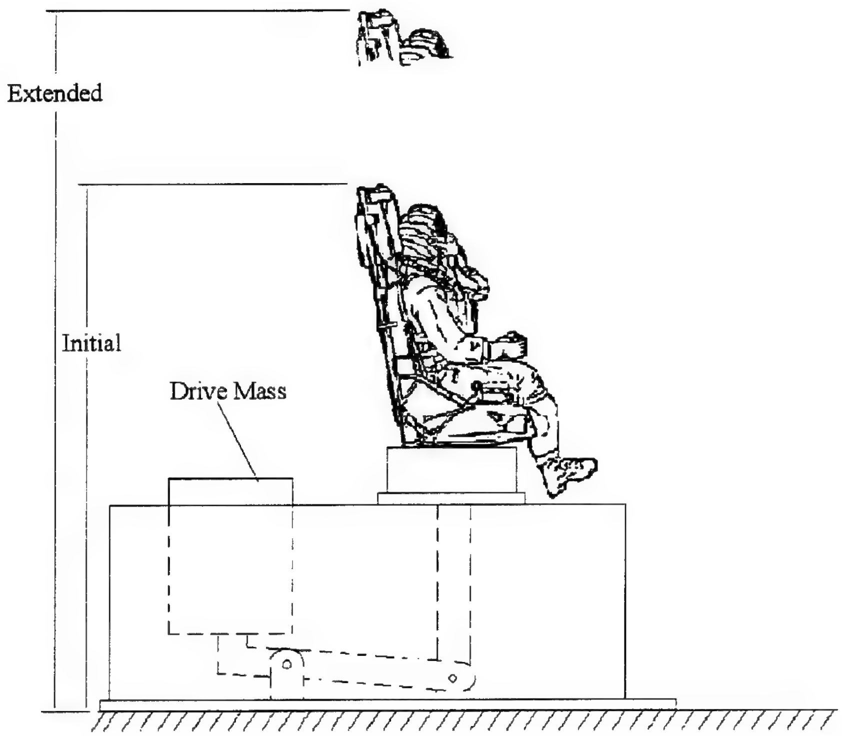


Figure 15 Counterweight Driven Calibration Platform

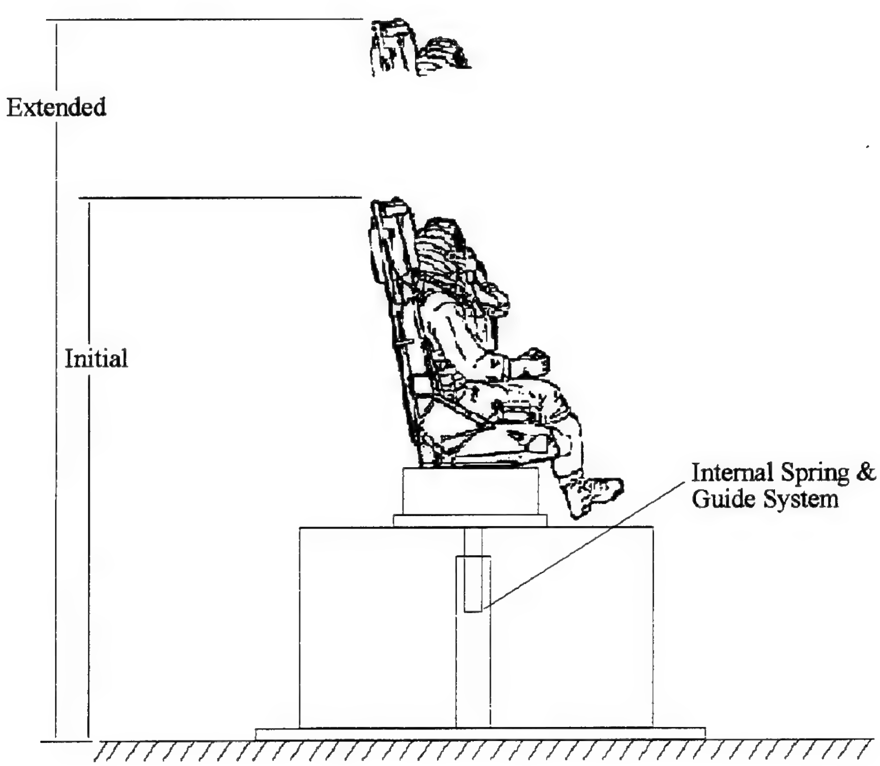


Figure 16 Spring Driven Calibration Platform

of the acceleration profile, is provided by hydraulic control cylinders located at the periphery of the platform. Both the acceleration and deceleration of the platform is computer controlled through the hydraulic control units.

The hydraulic control cylinders are essentially closed circuited with the fluid from one side of the piston flowing through a control valve and to the opposite end of the hydraulic cylinder. The control of the fluid flow through the control valves serves to control the cylinder motion and in turn controls the platform motion and acceleration. The hydraulic control cylinders control platform motion against the force provided by the pneumatic drive unit. The hydraulic flow through the control valves, and therefore platform acceleration, can be controlled to yield any acceleration profile described by the computer.

6.2.2 Analytical Formulation and Development of Concept #1

In this arrangement, a large area pneumatic cylinder or air type bladder is used to provide the force necessary to drive the acceleration platform. The large area cylinder or air bladder allows for the creation of a large acceleration force at relatively low operating pressure. Precharging the cylinder to a pressure greater than the minimum pressure required for the acceleration profile, utilizes the large volume of the cylinder as a charging chamber. This reduces, and depending upon total stroke requirements, may eliminate the need for an external charging chamber. If the compressed air required by the acceleration stroke is larger than that available from the cylinder or air bladder, an external charging chamber can be coupled directly to the power cylinder without the need for flow control or control orifices. The pressure required to drive the platform is dependent upon the maximum acceleration that is required. The volume of the charging chamber and cylinder is dependent upon the charging pressure and the length of the power stroke that is required.

Selection and sizing of the system components, such as the area of the pneumatic drive cylinder, charging pressure, charging volume, and sizing of the hydraulic control cylinders is based on the required acceleration loads. The acceleration loading for calibration, reference 3 g sine profile, short duration ejection simulation, reference Appendix "B", and crashworthy simulation, reference Appendix "C", establish the maximum driving force, maximum velocity and displacement requirements. Evaluation of the system for selection of components for these requirements indicate that these requirement can be satisfied with standard equipment components.

However, concept #1 is based on the application of a closed loop, computer controlled, electro-hydraulic servo valve system as the means of controlling the acceleration profile of the test/calibration platform. This type of system is essentially a velocity type of control with the acceleration of the system controlled by controlling the rate of change of velocity. Review and analysis of this type of control for the high onset rates and rapid velocity changes required by this application indicates that this approach to control of the acceleration platform would not provide adequate control. Very rapid response and high flow hydraulic valves would be required for control of this system. Based on an analysis of the acceleration on-set rates, the maximum velocity required, and the instantaneous power requirements for this application, and applying these requirements to the valve requirements, the servo control response requirements, and the

available servo equipment and techniques, it is determined that the use of electro-hydraulic servo controls to control the pneumatically driven acceleration platform, as presented for concept #1, is not feasible. Electro-hydraulic servo valves capable of operating within the limited response time required by the acceleration profiles are not available.

6.2.3 Evaluation of Concept #1

Electro-hydraulic servo valves for the control of acceleration as required by concept #1 are not available or feasible to meet the high response requirements of this application. As such, concept #1 is not an acceptable concept for the development of the manikin system test/calibration fixture. As such, it is necessary to select and evaluate alternative drive and control techniques for the manikin system test/calibration fixture.

6.3 Concept #2: Air Over Hydraulic, Hydraulically Controlled, Off-Center Drive, Acceleration Platform

6.3.1 Description of Concept #2

In concept #2, hydraulic cylinders are used to support the acceleration platform and provide both the drive and control of the accelerometer platform. Control of the acceleration platform, including determination of the acceleration profile, is accomplished by electro-hydraulic valves used to control flow to the hydraulic cylinders and therefore control the motion of the hydraulic drive cylinders. This drive system concept, commonly used in motion control platforms, is expected to provide control of platform acceleration to any acceleration profile described by the computer. Deceleration can be accomplished by braking on the guide rail or by providing an extended stroke on the hydraulic cylinder and using the hydraulic cylinder to allow computer control of both acceleration and deceleration. Guidance of the platform is provided by a rail system with linear ball bearings or a pre-loaded roller system. As shown, acceleration is provided in the vertical direction. The manikin and seat are shown as being mounted on the acceleration platform in the upright position but can be mounted in any desired test position.

The energy required to power the acceleration platform through a test cycle is provided by compressed air in a charge chamber. The compressed air is used to drive a pneumatic cylinder and the pneumatic cylinder is mechanically coupled to a hydraulic cylinder. This hydraulic cylinder is used as a compressor with pressure step-up. This provides high pressure fluid for operation of the hydraulic actuators. Computer-controlled, electro-hydraulic valves are used to control the motion and acceleration of the hydraulic cylinders. This, in turn, controls the platform motion and acceleration. The pressure required to drive the platform is dependent upon the maximum acceleration that is required by the system requirements. The volume of the charging chamber and cylinder is dependent upon the charging pressure and the length of the power stroke that is required.

6.3.2 Analytical Formulation and Development of Concept#2

Concept #2 is intended to utilize electro-hydraulic servo valves as the means of controlling the flow of hydraulic fluid and therefore the acceleration profile of the test/calibration platform. Based on the analysis of the acceleration on-set rates, the instantaneous power requirements and the speed requirements, as identified under task 1 of this project, and comparing these requirements with the valve requirements, the servo control response requirements, and the available servo equipment and techniques, it is determined that the use of electro-hydraulic servo controls for the drive system, as outlined in the proposed concept #2 is not feasible. Electro-hydraulic servo valves capable of operating within the limited response time of the required acceleration profiles are not available. The delivery of the high flow rates and acceleration forces that are required is not physically possible with standard equipment or techniques.

6.3.3 Evaluation of Concept #2

Electro-hydraulic servo valves for the control of acceleration as required by concept #2 are not available or feasible to meet the high response requirements of this application. As such, concept #2 is not an acceptable concept for the development of the manikin system test/calibration fixture. As such, it is necessary to select and evaluate alternative drive and control techniques for the manikin system test/calibration fixture.

6.4 Concept #3: Air Over Hydraulic, Hydraulically Controlled, Off-Center Drive, Acceleration Platform With Adjustable Acceleration Vector

6.4.1 Description of Concept #3

In this concept, reference Figure 11A and 11B, the drive system operation is intended to be identical to concept #2 above. The difference between concepts #2 and #3 is that the drive cylinder and drive system mechanical components in concept #3 are configured and mounted in such a way that the system can be positioned to provide acceleration and calibration for both horizontal and vertical motions. Intermediate positions between the horizontal and vertical positions are also available with this assembly.

Similar to concept #2, hydraulic cylinders are used to support the acceleration platform and to provide both the drive and control of the acceleration platform. Control of the acceleration platform, including determination of the acceleration profile, is accomplished by electro-hydraulic valves used to control the motion of the hydraulic drive cylinders. The platform acceleration is to be controlled to any acceleration profile described by the computer. Deceleration can be accomplished by braking on the guide rail or by providing an extended stroke on the hydraulic cylinder and using the hydraulic cylinder to allow computer control of both acceleration and deceleration. Guidance is provided by a rail system with linear ball bearings or a pre-loaded roller system. As shown in Figures 8A and 8B, the assembly is adjustable such that acceleration can be provided at any angle between horizontal and vertical and including both the horizontal and vertical positions. The manikin and seat are shown as being mounted on the acceleration platform in the upright position but can be mounted in any desired test position.

The energy required to power the acceleration platform through a test cycle is provided by compressed air in a charge chamber. The compressed air is used to drive a pneumatic cylinder and the pneumatic cylinder is mechanically coupled to a hydraulic cylinder. This hydraulic cylinder is used to provide high pressure fluid for operation of the hydraulic actuators. Computer-controlled, electro-hydraulic valves are used to control the acceleration and motion of the hydraulic cylinders. This, in turn, controls the platform motion and acceleration. As such, the platform acceleration can be controlled to any acceleration profile described by the computer. The pressure required to drive the platform is dependent upon the maximum acceleration that is required. The volume of the charging chamber and cylinder is dependent upon the charging pressure and the length of the power stroke that is required.

6.4.2 Analytical Formulation and Development of Concept #3

Concept #3 is intended to utilize electro-hydraulic servo valves as the means of controlling the flow of hydraulic fluid and therefore the acceleration profile of the test/calibration platform. Based on the analysis of the acceleration on-set rates, the instantaneous power requirements and the speed requirements, as identified under task 1 of this project, and comparing these requirements with the valve requirements, the servo control response requirements, and the available servo equipment and techniques, it is determined that the use of electro-hydraulic servo controls for the drive system, as outlined in the proposed concept #3 is not feasible. Electro-hydraulic servo valves capable of operating within the limited response time of the required acceleration profiles are not available. The delivery of the high flow rates and acceleration forces that are required is not physically possible with standard equipment or techniques.

6.4.3 Evaluation of Concept #3

Electro-hydraulic servo valves for the control of acceleration as required by concept #3 are not available or feasible to meet the high response requirements of this application. As such, concept #3 is not an acceptable concept for the development of the manikin system test/calibration fixture. As such, it is necessary to select and evaluate alternative drive and control techniques for the manikin system test/calibration fixture.

6.5. Concept #4: Computer Programmed, Compressed Gas, Coaxial Drive, Vertical Motion Acceleration Platform

6.5.1 Description of Concept #4

The overall spatial configuration for this concept, reference Figure 12, is similar to the spatial parameters of concept #1 above. However, in lieu of the electro-hydraulic servo controlled drive presented for concept #1, this arrangement is powered by a compressed gas drive system. In this arrangement, the manikin system and seat is shown as being mounted on the acceleration platform in the upright position but can be mounted in any desired test position. The platform motion is perpendicular to the base of the assembly. Guidance is provided by a rail system with linear ball bearings or a pre-loaded roller system. The combined mass of the acceleration platform

and the manikin system is driven by a drive cylinder with the appropriate pressure and energy pre-established for a given test cycle. The drive energy is provided by a compressed gas, such as nitrogen, from a high pressure charge chamber. Motion control and control of the acceleration profile, is determined by the proper pre-test setting of valves, chamber volumes, initial chamber pressures, platform load and related operational components of the system. The prerequisite settings for each of these control elements is established by computer simulation prior to the set-up of the test.

Evaluation of a concept #4 requires the development and identification of the details of the alternative compressed gas drive arrangements. It requires a review, development and analysis of potential alternatives for the compressed gas drive such that a satisfactory and optimal drive is selected with the capability of meeting the acceleration profiles intended for use in the manikin system test/calibration fixture.

Six compressed gas drive arrangements are identified as candidate drive alternatives for inclusion in concept #4. Each of these six alternative drive systems consist of specialized gas and hydraulic components that are configured and coupled in an arrangement that provides a drive system which is expected to adequately meet the acceleration and load requirements of the test/calibration system. Each of these six alternative drive systems are evaluated below in order to determine its ability to satisfy the drive system requirements.

6.5.2 Analytical Formulation and Development of Concept#4

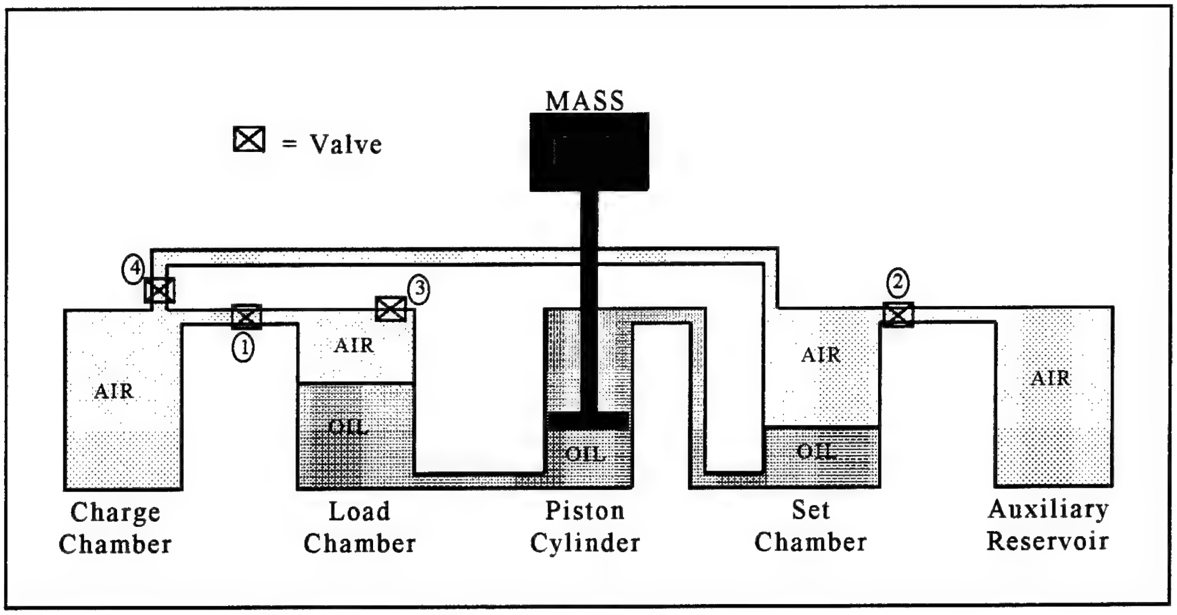
The selection of an optimal compressed gas drive system is required in order to complete the development of concept #4. This requires the identification and development of alternative drive systems for evaluation and development. Selection and sizing of system components for the drive system of concept #4, such as the area of the pneumatic drive cylinder, adequate charging volume, charging pressure, and sizing of the hydraulic control cylinders must be established through the analysis of the compressed gas drive alternatives.

Various compressed gas drive arrangements are established and analytical procedures are formulated for the evaluation and development of the various conceptual drive arrangements. These items are utilized in the development of the drive concepts. Analytical procedures are formulated to provide a means of determining engineering estimates of system components and drive system performance. The selection of the optimal compressed gas drive concept for concept #4 is based on the identification of drive alternatives, the formulation of analytical procedures to evaluate the drive alternatives and a final selection of an optimal drive concept.

6.5.2.1 Compressed Gas Drive Alternatives

<u>Drive Concept "A"</u>

Drive concept "A", reference the drive system schematic shown in Figure 17, utilizes a large chamber of compressed air to both drive and brake the test platform and manikin. The drive assembly consists of a charge chamber, load chamber, drive cylinder, set chamber, auxiliary



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Set Chamber Volume:	325.0 in^3
Auxiliary Reservoir Volume:	20.0 in^3
Piston Diameter:	2.5 in
Rod Diameter:	1.0 in
Maximum Available Stroke:	14.5 in

Valve Description

#1: Pneumatic valve used to charge load chamber.
#2: Pressure relief valve. (Only used for calibration pulse.)
#3: Load chamber pressure vent to ambient.
#4: Pneumatic valve used to charge set chamber.

Sequencing Steps

1. Valve #1 is opened; initiating acceleration.
2. Valve #2 provides pressure relief when necessary.
3. Valves #3 & #4 open and valve #1 closes; initiating braking.
4. Valves #3 & #4 close and valve #1 re-opens; bringing system to rest.

Figure 17 Drive Concept "A", Compressed Gas Over Oil Configuration

reservoir and valves and plumbing to control the acceleration profile for the various conditions of calibration, ejection testing and crashworthy seat testing. This system utilizes hydraulic fluid on both sides of the drive piston with a compressed gas, such as nitrogen, driving the hydraulic fluid. The piston diameter selected for this concept is 2.5 inches. Chamber volumes for the operating gas is set by adjusting the level of hydraulic fluid in the chambers. The drive system can be programmed to meet various acceleration profiles for calibration, ejection testing and crashworthy seat testing by proper setting of the system parameters such as selection of the initial charge pressure, back pressure, load chamber volume, set chamber volume and timing of the various valves. The drive system settings are set or programmed through the use of a computer program simulation which evaluates the drive response characteristics and the test cycle conditions and determines the proper settings for the specific test subject weight and desired acceleration profile. The system requires proper timing of the valve used to pressurize the set chamber with charge chamber gas in order to accomplish adequate braking of the system. Design data and estimates of acceleration profiles for a given set of system parameters and test conditions are presented in Appendix “E”.

Drive Concept "B"

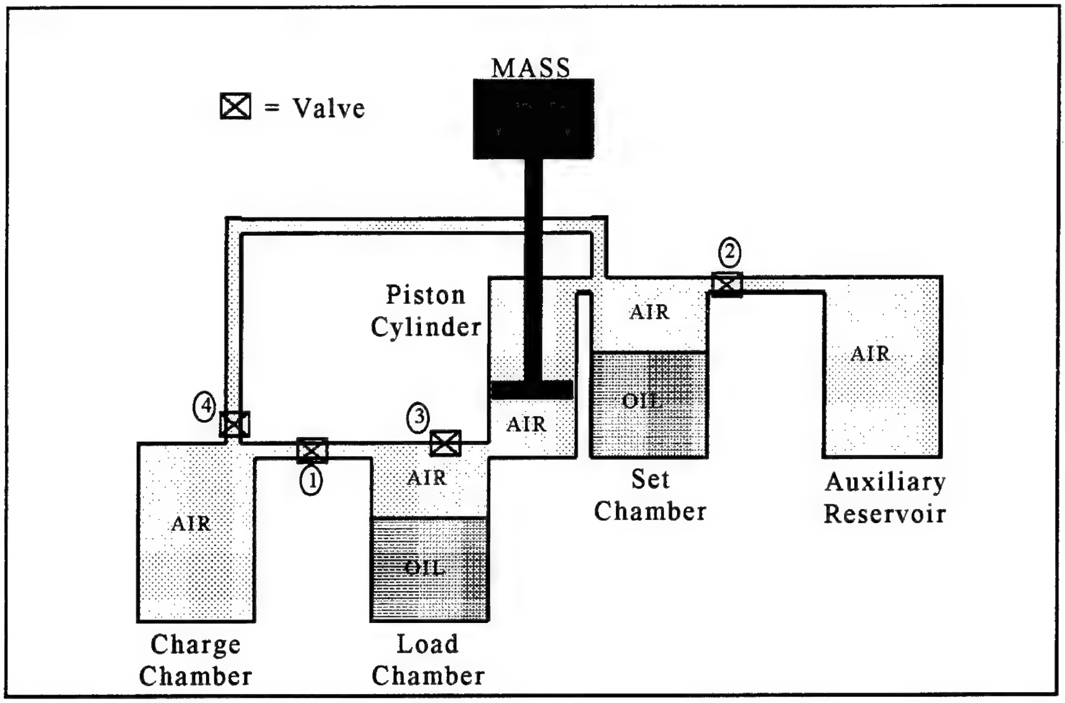
Drive concept "B", shown in Figure 18, is similar to concept "A" except that this arrangement does not use hydraulic fluid on either side of the drive piston but rather provides that the charge gas, that is either compressed air or nitrogen, is placed in direct contact with the drive piston. In addition, the drive piston size is increased from 2.5 inch diameter to 3.25 inch diameter. The increase in piston size allows a significant reduction in charge pressure (3000 psi to 1750 psi) but requires increased flow rates. Charge gas at the drive piston requires high pressure gas seals at the drive piston. As is the case with drive concept "A", this system requires proper timing of the valve used to pressurize the set chamber with charge chamber gas in order to accomplish adequate braking of the system. Design data and estimates of acceleration profiles for a given set of system parameters and test conditions are presented in Appendix “E”.

Drive Concept "C"

Drive concept "C", shown in Figure 19, is an enhancement of drive concept "B" in that the timing of the valve used to pressurize the set chamber from the charge chamber is eliminated by precharging the set chamber to an appropriate pressure. Design data and estimates of acceleration profiles for a given set of system parameters and test conditions are presented in Appendix “E”.

Drive Concept "D"

Drive concept "D", shown in Figure 20, utilizes a large chamber of compressed air at high pressure to drive the test platform and manikin. The drive assembly consists of a charge chamber, load chamber, drive cylinder, oil reservoir, and valves. The drive cylinder is constructed with a floating piston to incorporate an internal set chamber into the drive cylinder with the overall arrangement providing control of the acceleration profile for the



<u>Concept Specifications</u>

Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Set Chamber Volume:	325.0 in^3
Auxiliary Reservoir Volume:	20.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Maximum Available Stroke:	14.5 in

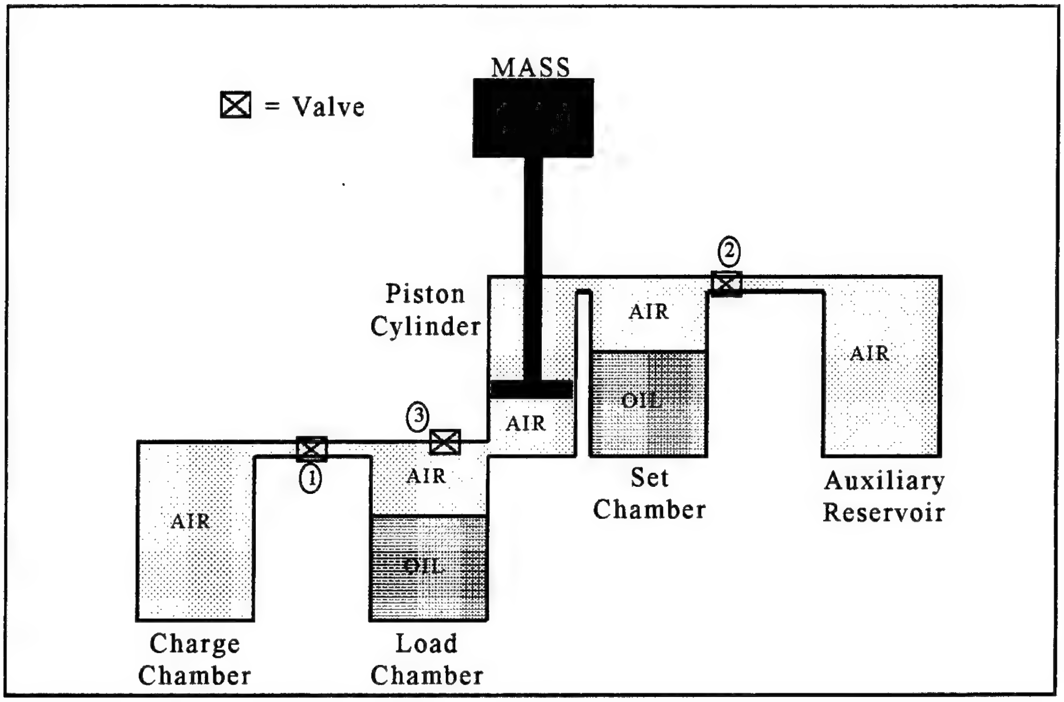
<u>Valve Description</u>

#1: Pneumatic valve used to charge load chamber.
#2: Pressure relief valve. (Only used for calibration pulse.)
#3: Load chamber pressure vent to ambient.
#4: Pneumatic valve used to charge set chamber.

<u>Sequencing Steps</u>

1. Valve #1 is opened; initiating acceleration.
2. Valve #2 provides pressure relief when necessary.
3. Valves #3 & #4 open and valve #1 closes; initiating braking.
4. Valves #3 closes and valve #1 re-opens; bringing system to rest.

Figure 18 Drive Concept "B", Compressed Gas Drive



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Set Chamber Volume:	325.0 in^3
Auxiliary Reservoir Volume:	20.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Maximum Available Stroke:	24.5 in

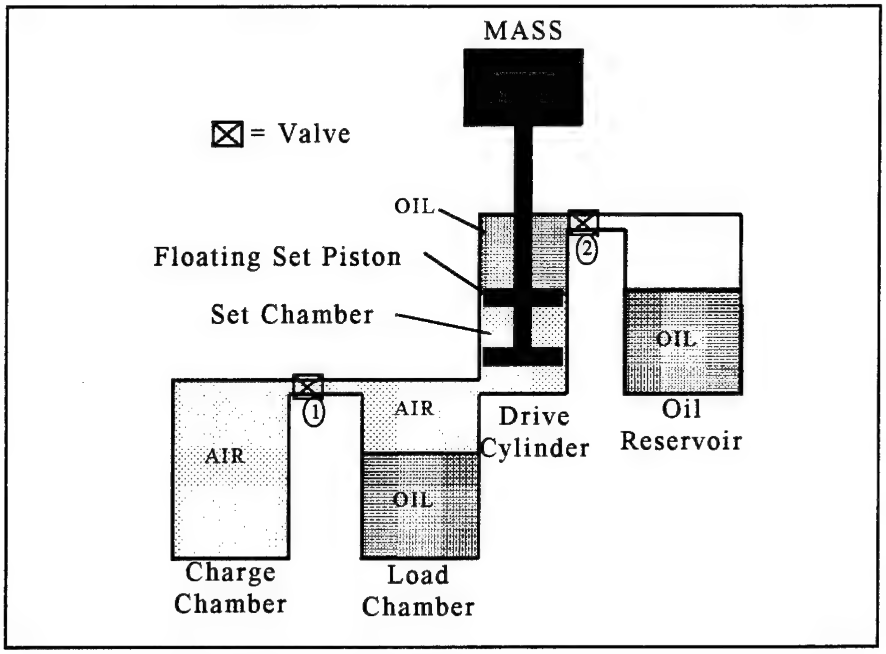
Valve Description

#1: Pneumatic valve used to charge load chamber.
#2: Pressure relief valve. (Only used for calibration pulse.)
#3: Load chamber pressure vent to ambient.

Sequencing Steps

1. Valve #1 is opened; initiating acceleration.
2. Valve #2 provides pressure relief when necessary.
3. Valve #3 opens and valve #1 closes; initiating braking.
4. Valves #3 closes and valve #1 re-opens; bringing system to rest.

Figure 19 Drive Concept “C”, Compressed Gas Drive



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Oil Reservoir Volume:	325.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Maximum Available Stroke:	14.0 in

Valve Description

#1: Pneumatic valve used to charge load chamber.
#2: Ideal pressure relief valve.

Sequencing Steps

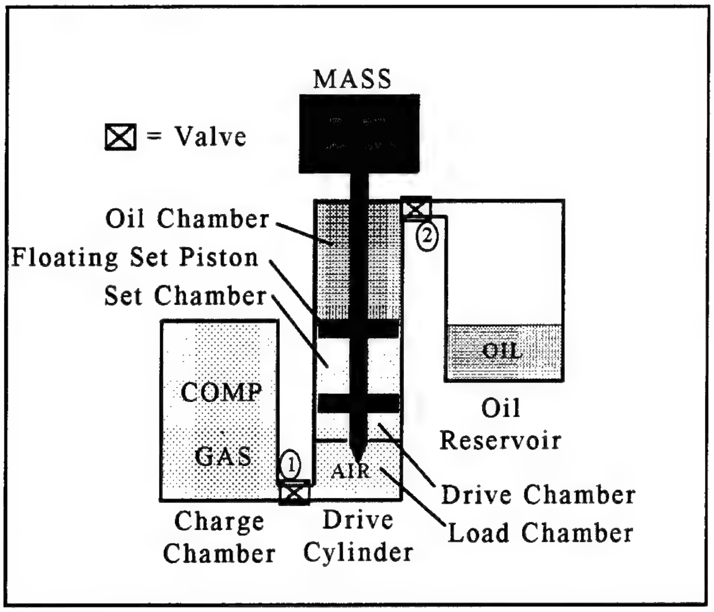
1. Valve #1 is opened; initiating acceleration.
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

Figure 20 Drive Concept "D", Compressed Gas Driven With Internal Set Chamber

various conditions of calibration, ejection testing and crashworthy seat testing. This system utilizes hydraulic fluid on the braking side of the floating piston with air, or nitrogen, from the charge chamber used to drive the drive piston. The piston diameter for this concept is 3.25 inches. Initial acceleration onset is determined by the load chamber volume which in turn is set by adjusting the level of hydraulic fluid in the load chamber. The drive system can be programmed to meet various acceleration profiles for calibration, ejection testing and crashworthy seat testing by proper setting of the system parameters such as selection of the initial charge pressure, load chamber volume, set chamber volume and pressure relief valve setting. The drive system settings are set or programmed through the use of a computer simulation which simulates the drive response characteristics and the test cycle conditions and determines the proper settings for the specific test subject weight and desired acceleration profile. The system is considered superior to drive concepts "A" and "B" in that there is no requirement for proper timing of any of the valves. Design data and estimates of acceleration profiles for a given set of system parameters and test conditions are presented in Appendix “E”.

Drive Concept "E"

Drive concept "E", shown in Figure 21, utilizes a large chamber of compressed air at high pressure (2250 psi) to drive the test platform and manikin. The drive assembly consists of a charge chamber, drive cylinder, oil reservoir, and valves as illustrated in the schematic. The drive cylinder is constructed with a floating piston to incorporate an internal set chamber into the drive cylinder. A metering pin and control orifice is incorporated into the drive cylinder with the overall arrangement providing control of the acceleration profile for the various conditions of calibration, ejection testing and crashworthy seat testing. An optimal sine wave for acceleration for calibration is achieved by positioning the start position such that the orifice at the metering pin is open and the base of the drive cylinder acts as a loading chamber to properly profile the sine wave onset. Compressed gas from the charge chamber, either air or nitrogen, is metered through the metering orifice to drive the test platform. The combination of the metering of the compressed gas through the metering orifice and the compression of the gas in the set chamber serves to establish the proper acceleration profile. Hydraulic fluid is metered through relief valve to brake the test platform after the completion of the test acceleration profile. The piston diameter for this concept is 3.25 inches. Initial acceleration onset is determined by the load chamber volume for the calibration test cycle. The drive system can be programmed to meet various acceleration profiles for calibration, ejection testing and crashworthy seat testing by proper setting of the system parameters such as selection of the initial charge pressure, load chamber volume, set chamber volume and pressure relief valve setting. The drive system settings are set or programmed through the use of a computer simulation which simulates the drive response characteristics and the test cycle conditions and determines the proper settings for the specific test subject weight and desired acceleration profile. The system is superior to drive concepts "A" and "B" in that there is no requirement for proper timing of any of the valves. Design data and estimates of acceleration profiles for a given set of system parameters and test conditions are presented in Appendix “E”.



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Oil Reservoir Volume:	325.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Total Piston Cylinder Length:	21.0 in
Load Chamber Length:	3.0 in

Metering Pin

Diameter:	1.375 in
Total Length:	3.75 in
Variable Diameter Length:	2.75 in
Orifice Diameter:	1.375 in

Valve Description

#1: Pneumatic valve used to charge load chamber of the Piston Cylinder.
#2: Ideal pressure relief valve.

Sequencing Steps when using Valve #1

1. Valve #1 is opened; initiating acceleration. (Metering pin starts above orifice.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

Sequencing Steps when not using Valve #1

1. Acceleration is initiated through release of metering pin. (The load chamber of the piston cylinder is in equilibrium with the charge chamber at all times.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

Figure 21 Drive Concept "E", Compressed Gas With Internal Set Chamber and Needle Metering Orifice

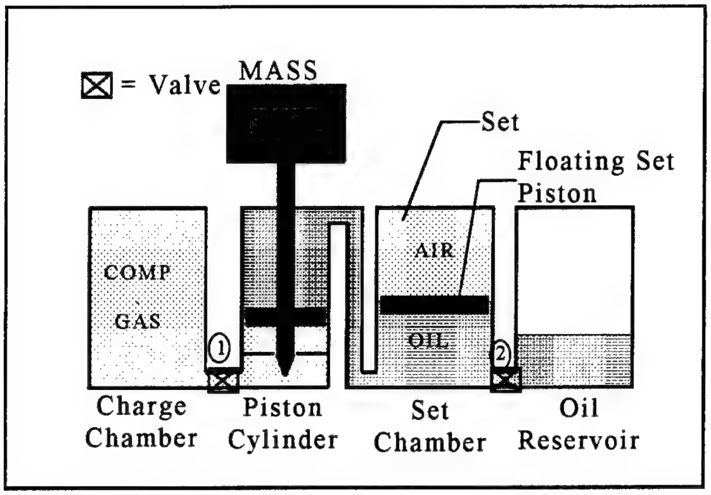
Drive Concept "F"

Drive concept "F", shown in Figure 22, utilizes a large chamber of compressed air at high pressure (2250 psi) to drive the test platform and manikin. The drive assembly consists of a charge chamber, drive cylinder, oil reservoir, and valves as illustrated in the schematic. The drive cylinder is constructed with a floating piston to incorporate an internal set chamber into the drive cylinder. A metering pin and control orifice is incorporated into the drive cylinder with the overall arrangement providing control of the acceleration profile for the various conditions of calibration, ejection testing and crashworthy seat testing. An optimal sine wave for acceleration for calibration is achieved by positioning the start position such that the orifice at the metering pin is open and the base of the drive cylinder acts as a loading chamber to properly profile the sine wave onset. Compressed gas from the charge chamber, either air or nitrogen, is metered through the metering orifice to drive the test platform. The combination of the metering of the compressed gas through the metering orifice and the compression of the gas in the set chamber serves to establish the proper acceleration profile. Hydraulic fluid is metered through relief valve to brake the test platform after the completion of the test acceleration profile. The piston diameter for this concept is 3.25 inches. Initial acceleration onset is determined by the load chamber volume for the calibration test cycle. The drive system can be programmed to meet various acceleration profiles for calibration, ejection testing and crashworthy seat testing by proper setting of the system parameters such as selection of the initial charge pressure, load chamber volume, set chamber volume and pressure relief valve setting. The drive system settings are set or programmed through the use of a computer simulation which simulates the drive response characteristics and the test cycle conditions and determines the proper settings for the specific test subject weight and desired acceleration profile. The system is superior to drive concepts "A" and "B" in that there is no requirement for proper timing of any of the valves. Design data and estimates of acceleration profiles for a given set of system parameters and test conditions are presented in Appendix “E”.

6.5.2.2 Computer Model for Compressed Gas Drive Alternatives

The formulation of a computer simulation for the alternative compressed gas drive systems, drive concepts "A" through "F", provides for the convenient dynamic analysis of various combinations of the compressed gas drive alternatives. Utilizing identical pneumatic and hydraulic components, different combinations of chamber pressures, air/oil ratios, and valve and pipe sections are evaluated to determine the capability of a design arrangement to reproduce a wide range of acceleration profiles. The primary control elements that can be adjusted to achieve the desired results are the chamber pressures, the air and oil ratios, the valve and pipe configurations, and the valve control schedule.

Input to the computer simulation is accomplished through an input file which contains simulation run parameters, chamber and cylinder dimensions, valve and piping parameters, initial chamber pressures, air/oil distribution, and air and oil physical properties. These values are read into the program and used to generate the initial model setup. The initial setup routine computes the chamber volumes and initial air and oil volume in each chamber. The initial pressures on both side of the piston are calculated assuming the system is in equilibrium.



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Oil Reservoir Volume:	325.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Total Piston Cylinder Length:	21.0 in
Load Chamber Length:	3.0 in

Metering Pin

Diameter:	1.375 in
Total Length:	3.75 in
Variable Diameter Length:	2.75 in

Orifice Diameter:	1.375 in

Valve Description

#1: Pneumatic valve used to charge load chamber of the Piston Cylinder.
#2: Ideal pressure relief valve.

Sequencing Steps when using Valve #1

1. Valve #1 is opened; initiating acceleration. (Metering pin starts above orifice.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

Sequencing Steps when not using Valve #1

1. Acceleration is initiated through release of metering pin. (The load chamber of the piston cylinder is in equilibrium with the charge chamber at all times.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

Figure 22 Drive Concept "F", Compressed Gas Drive With External Set Chamber and Needle Orifice

Initial air densities are calculated as function of pressure and temperature in each of the chambers. Finally, the total mass of oil in the system is found from the chamber volumes and the specified oil fractions.

6.5.2.3 Final Selection of Drive Alternative

The basic premise or requirement for the development of the alternative drive systems is that the drives be programmable and be able to provide a complete 3g sine wave over a 100 ms period, be able to simulate the first 80ms of the ejection seat operation and be able to simulation crash loading up to 20g's with 25ms duration. The drive system must be programmable to be able to select and simulate the various acceleration conditions.

There are a number of considerations in evaluating the alternative drive arrangements. The timing, operational requirements and reliability of valves used in any arrangement is considered a significant issue. Elimination or reduction in the number of valves is considered to improve the overall design concept. There are advantages and disadvantages in a fully pneumatic system. In concepts "B" and "C", the oil in the system is a static component that is used to adjust the available gas volume of the chambers. This can be considered an advantage when considering the minimum response time of the system, since a lower mass, less viscous fluid element needs to be accelerated to generate platform motion. Oil in the cylinder has advantages from the standpoint of providing better opportunities for control and better opportunities for lubrication and sealing. A disadvantage of pneumatic cylinders is that they are difficult to seal at high pressures. The large volumes of high pressure gas must be evaluated from the standpoint of safety in order to ensure safe operation of the system.

Based on the results of the analysis of the various alternative compressed gas drive systems the compressed gas drive concept “F” is judged to be the optimal drive system. To a large extent, this drive system is a development based on the analytical estimates development of design trade-offs from the other alternatives. This drive concept meets all of the performance requirements for the manikin system calibration test fixture. Selection of this drive concept and defining this drive as the drive system for manikin system test/calibration fixture concepts #4, #5 and #6 establishes that these concepts meet the drive performance requirements.

6.5.3 Evaluation of Concept #4

Concept #4 meets all of the parameters and specifications for the manikin system test/calibration fixture.

6.6 Concept #5: Computer Programmed, Compressed Gas, Off-Center Drive, Vertical Motion Acceleration Platform

6.6.1 Description of Concept #5

The overall spatial configuration for this concept, shown in Figure 13, is similar to the spatial

parameters of concept #2 above. However, in lieu of the electro-hydraulic servo controlled drive presented for concept #2, this arrangement is powered by a programmable compressed gas drive system as described by concept "F" above and shown in the schematic, reference Figure 22. In this arrangement, the manikin system and seat is shown as being mounted on the acceleration platform in the upright position but can be mounted in any desired test position. The platform motion is perpendicular to the base of the assembly. Guidance for platform motion is provided by a rail system with linear bearings. The combined mass of the acceleration platform and the manikin system is driven by a drive cylinder with the appropriate pressure and energy pre-established for a given test cycle. The drive energy is provided by a compressed gas, such as nitrogen, from a high pressure charge chamber. Motion control and control of the acceleration profile, is determined by the proper pre-test setting of valves, chamber volumes, initial chamber pressures, platform load and related operational components of the system. The prerequisite settings for each of these control elements is established by computer simulation prior to the set-up of the test.

6.6.2 Analytical Formulation and Development of Concept#5

The selected drive system and the analytical formulation of the system is the same as for concept #4 above, reference section 6.5.2 and 6.5.3

6.6.3 Evaluation of Concept #5

Concept #5 meets all of the parameters and specifications for the manikin system test/calibration fixture.

6.7 Concept #6: Computer Programmed, Compressed Gas, Off-Center Drive, Acceleration Platform With Adjustable Variable Oriented Acceleration Vector

6.7.1 Description of Concept #6

The overall spatial configuration for this concept, shown in Figure 14A and 14B, is similar to the spatial parameters of concept #3 above. However, in lieu of the electro-hydraulic servo controlled drive presented for concept #3, this arrangement is powered by a programmable compressed gas drive system as described by concept "F" above and shown in the schematic, reference Figure 22. In this arrangement, the manikin system and seat is shown as being mounted on the acceleration platform in the upright position but can be mounted in any desired test position. The platform motion is adjustable from 80 degrees to 90 degrees relative to the base of the assembly. Guidance for the platform motion is provided by a rail system with linear bearings. The combined mass of the acceleration platform and the manikin system is driven by a drive cylinder with the appropriate pressure and energy pre-established for a given test cycle. The drive energy is provided by a compressed gas, such as nitrogen, from a high pressure charge chamber. Motion control and control of the acceleration profile, is determined by the proper pre-test setting of valves, chamber volumes, initial chamber pressures, platform load and related operational components of the system. The prerequisite settings for each of these control elements is established by computer simulation prior to the set-up of the test.

6.7.2 Analytical Formulation and Development of Concept #6

The selected drive system and the analytical formulation of the system is the same as for concept #4 above, reference section 6.5.2 and 6.5.3

6.7.3 Evaluation of Concept #6

Concept #6 meets all of the parameters and specifications for the manikin system test/calibration fixture.

6.8 Counterweight Driven Calibration Platform

6.8.1 Description of Concept #7

In this concept, shown in Figure 15, a large mass is used with an appropriate mechanical leverage system in order to provide constant acceleration of a test manikin over a limited range of motion or time. Standard commercial shock absorbers can be used to brake the system and return the system to rest. The test acceleration is initiated by releasing the drive mass. Depending on the amount of mass used to drive the system and the amount of mechanical leverage provided by the design, this arrangement is able to provide a constant acceleration either equal to or even larger than the 3g required calibration acceleration.

6.8.2 Analytical Formulation and Development of Concept #7

Depending on the amount of mass used to drive the system and the amount of mechanical leverage provided by the design, this arrangement is able to provide a constant acceleration either equal to or greater than the 3g required calibration acceleration. If a 5 ton mass is selected as the drive element, the system would require a mechanical leverage of approximately one-to-six in order to provide a constant acceleration of 3g's on the manikin. The calculation of the mechanical leverage required to provide 3g acceleration on a combined manikin and test platform weight of 700 lbs is shown in Appendix "F".

6.8.3 Evaluation of Concept #7

This system produces an excitation pulse for calibration that is other than the sine wave profile. This system is appropriate for calibration testing at a constant acceleration for a short excitation period and is not able to simulate ejection or crashworthy acceleration profiles.

6.9 Concept #8: Spring Driven Calibration Platform

6.9.1 Description of Concept #8

In this concept, reference Figure 16, large compression springs are used to provide acceleration of a manikin system over a sufficient range of motion to accomplish calibration. The compression

springs can be sized to provide an initial acceleration corresponding to the specified 3g maximum acceleration and with the acceleration decreasing somewhat as the springs extend. The test acceleration is initiated by releasing the test platform. Standard commercial shock absorbers can be used to brake the system and return the system to rest.

6.9.2 Analytical Formulation and Development of Concept#8

Utilizing precision, heavy duty compression springs, the acceleration profile for the calibration of the manikin system with a combined manikin and test platform weight of 700lbs would be as shown in Appendix “G”.

6.9.3 Evaluation of Concept #8

This system produces an excitation pulse for calibration that is other than the a sine wave profile. Also, this system is not able to simulate ejection or crashworthy acceleration profiles and is therefore only appropriate for calibration testing with a preset excitation pulse and with the acceleration profile being a decreasing acceleration profile corresponding to the expansion of the springs.

7.0 SELECTION OF FINAL DESIGN

The selection of the final design is based on the design trade-offs corresponding to the various alternatives. The various design trade-offs are incorporated into the development of the alternative concepts with the ability of the test/calibration fixture to reproduce the required calibration, ejection simulation and crash test acceleration profiles being a primary consideration. These profiles must be achieved in a consistent manner. The ability of the alternative drive system arrangements to meet the acceleration profiles is evaluated by means of the analytical procedures presented in the Appendices.

The design alternatives generated by this project are evaluated and trade-offs with respect to the various details of the alternatives are selected in order to obtain an optimal design concept for satisfying or surpassing the specifications and parameters established for the manikin system test/calibration fixture. Trade-off evaluation, in the form of comparing the various alternatives with one another, are accomplished with consideration given to power source, type of drive, materials of construction, instrumentation, control strategies, method of mounting, manufacturing cost, sensitivity, reliability and accuracy.

Based on the various requirements and trade-offs, concept #4 is selected as the arrangement that best meets all of the manikin system test/calibration fixture requirements. Concept #4 provides an easily accessed method of mounting, is easily installed within a laboratory facilities, easy to operate and can be programmed to simulate and reproduce, in a consistent manner, the acceleration profiles for both calibration and short duration simulation. The cost for fabrication of concept #4 is estimated to be significantly less than either concept #5 or #6.

8.0 PROOF OF CONCEPT

The general arrangement for the selected concept is shown in Figure 12 and the preliminary design layouts presented in Appendix "A". A cross section of the preliminary layout of the selected concept is shown in Drawing # 96-C-0028-10 Sheet #2, reference Appendix "A". A schematic of the selected drive system is shown in Figure 18. This concept utilizes several pressure chambers in combination with a metering orifice within the drive cylinder in order to control the flow of compressed gas to the cylinder and thereby control the acceleration of the drive cylinder and connected payload.

The preliminary layouts incorporate four charge chambers of 2.5 gallon (613 cu. in.) each. The charge chambers are located 90 degrees apart around the base of the drive cylinder. The four charge chambers are interconnected on the chamber side, or therefore the compressed gas supply side, of the drive cylinder supply valve. The charge chambers are selected for a maximum operating pressure of 3000 psi. The four charge chambers are represented in the system schematic, reference Figure 18, as a single charge chamber.

A supply valve, used to retain the charge pressure within the charge chambers until the test cycle is to be initiated, is identified as valve #1 in the schematic. This valve, as designed and shown in the preliminary layout, is designed within the base of the drive cylinder assembly. When closed, this valve does not allow the flow of compressed gas to the load chamber or drive cylinder. When opened, the valve is designed such that the flow path from each of the four charge chambers are completely and simultaneously opened allowing the simultaneous and unrestricted delivery of the compressed gas from all four of the charge chambers. The supply valve is designed to move completely out of the flow path of all of the charge chambers in order to provide unrestricted flow of compressed gas from the charge chambers.

The open or closed positioning of the supply valve is controlled by an external pilot valve. With the external pilot valve positioned to conduct charge pressure from the supply or pressure charged side of the valve to the bottom of the valve, the charge valve is held in the closed position with the charge pressure retained within the charge chambers. Repositioning the external pilot valve such that the supply pressure is directed to the top of the supply valve and the bottom of the valve is vented to the atmosphere, then the valve spool will be forced to the open position, allowing the charge pressure to pass through the valve and into the load chamber of the drive cylinder. The entrance of the charge pressure into the load chamber will serve to rapidly drive the supply valve to a fully open position. The supply valve is designed to move completely out of the flow path of all of the charge chambers in order to provide unrestricted flow of compressed gas from the charge chambers.

In the schematic of the drive system, a volume identified as the load chamber volume is incorporated into the conceptual arrangement as a means of controlling cylinder pressure build-up and thereby allowing control of the initial onset of the acceleration forces. A larger load chamber serves to increase the cushioning of the initial onset acceleration. Proper scaling and setting of

this volume prior to test cycle initiation provides for programming the initial onset rate for the loading and acceleration.

As shown in the preliminary layouts, the body of the supply valve is designed with a small volume, or space, provided within the supply valve body between the valve spool and the bottom face of the drive cylinder piston. Positioning the drive piston away from the its extreme bottom position by setting the cylinder at some initial stroke displacement, increases this volume from a minimum value to a larger value controlled by the initial stroke displacement setting of the drive cylinder. This total volume, that is the volume within the supply valve body and the volume provided by the initial setting of the drive piston, is therefore adjustable and, as required by the parameters of a specific test cycle, the load chamber volume can be increased by positioning the drive piston at something other than the zero stroke position. Therefore, as provided by the preliminary layouts, the load chamber volume is adjustable and allows for the presetting or programming of a larger or smaller initial onset rate into the test cycle as required or desired for a specific set of test conditions. This design arrangement serves as the embodiment of the adjustable load chamber volume indicated in the schematic.

A metering pin and orifice is incorporated into the layouts as shown in the cross sectional view of the drive system, reference Drawing # 96-C-0028-10 Sheet #2. The design details of this metering pin arrangement is determined in the analysis of the drive system, reference Appendix "A". This metering pin and control orifice, in combination with the adjustment provided for the load chamber volume discussed above, serves to provide adequate adjustment techniques to program the initial ramping or onset for the acceleration loading of the manikin system test/calibration platform and attached manikin system.

As shown in the drive system schematic, the drive piston is driven by compressed gas provided by the charge chambers. As also shown in the schematic, the cylinder volume on the rod side of the drive piston is filled with hydraulic fluid. This hydraulic media provides a number of desirable design features and is used to meet a number of drive system requirements. For example, the hydraulic media is used to assist in the control and programming of the acceleration of the test platform and attached manikin system. The hydraulic media is also used to generate a back pressure that is sufficient to brake the drive system, platform and attached load within the cylinder travel allowed by the design. In addition, the hydraulic media allows the inclusion of a standard type shock absorber to protect the drive cylinder from excessive shock loads at the end of the cylinder stroke.

The motion of the floating set piston is coupled to the drive piston by the incompressible hydraulic fluid between the two pistons. Motion of the drive piston causes motion of the set piston with the gas contained within the set chamber being compressed by the motion of the floating piston and creating a backpressure. The backpressure acts on the rod side of the drive piston and serves to counteract the charge pressure on the piston. As the backpressure builds, it influences the acceleration of the platform and the attached manikin system. The buildup of backpressure eventually increases sufficiently to reverse the total forces on the drive piston and therefore reverses the acceleration of the platform. The rate of the buildup of the backpressure is controlled by the sizing and initial pressure setting of the set chamber.

A floating piston type accumulator is incorporated into the preliminary design layouts and is assembled to the drive cylinder. The accumulator is hydraulically coupled to the hydraulic media on the rod end of the drive cylinder. Before initiation of the test cycle, this accumulator is to be pressurized to the level of deceleration desired in the braking and stopping of the platform and attached manikin system. In operation, once the buildup of pressure in the set chamber becomes equal to the precharged pressure in the piston accumulator, the hydraulic fluid is dumped into the accumulator at the accumulator pressure. This ensures that the backpressure does not increase to an unsafe level and it also serves to control the maximum deceleration in braking.

As shown in the cross section of the drive system, the drive cylinder also has a standard hydraulic cushion built into the rod end of the cylinder. This cushion serves as a backup braking device to ensure that the drive rod is not slammed into the cylinder head in the case of a platform overload or an inadequate pressure setting at the discharge or braking of the drive.

Setup or programming of the manikin system test/calibration system for a specific test or calibration cycle is accomplished by performing a computer simulation of the desired test cycle and utilizing that computer simulation to determine the proper settings for the required preset variables of the fixture. The components of the drive system must than be set to the proper settings as determined by the computer simulation. In this manner, the manikin system test/calibration can be programmed to provide a specified test cycle. Various test cycles can be performed by determining proper preset conditions through computer simulation of each desired test cycle and than setting the system parameters to the determined values.

Utilizing the analytical procedures formulated within this program, computer simulation of the following test/calibration cycles has been used to determine the preset conditions required to reproduce the respective test/calibration cycle with a 400 lb manikin and fixture test weight and a 300lb platform weight. The predetermined preset conditions and estimated output of the manikin system test/calibration system for calibration, ejection simulation and crash testing is provided below.

<u>Manikin System Calibration With 3g Sine Wave</u>

The preset parameters for calibration of a manikin system with sine wave excitation having a maximum acceleration of 3g's and a period of 100ms are shown in Figure 22. The comparison of estimated results with the desired input profiles for acceleration are shown in Appendix “E”.

<u>Short Duration Ejection Simulation</u>

The preset parameters for simulation of the first 80ms of the actual ejection as obtained from the operational analysis accomplished in section 4.0 above are shown in Figure 22. The estimated results and comparison with the desired acceleration profile are shown in Appendix “E”.

Short Duration Crash Simulation

The preset parameters for simulation of the first 25ms of the crash cycle as obtained from the operational analysis accomplished in section 4.0 above is shown in Figure 22. The estimated results and comparison with the desired acceleration profile are shown in Appendix “E”.

Conclusions

The analytical results for the three selected test/calibration conditions establish that the preliminary design presented in Appendix "A" meets the overall system requirements.

9.0 PRELIMINARY DESIGN LAYOUTS

A detailed conceptual design for the manikin system test/calibration fixture has been completed under this project and is presented in the preliminary design layouts presented in Appendix "A" of this report. The preliminary design layouts represent a more detailed development of the concept #4 and incorporates the basic features of this selected concept.

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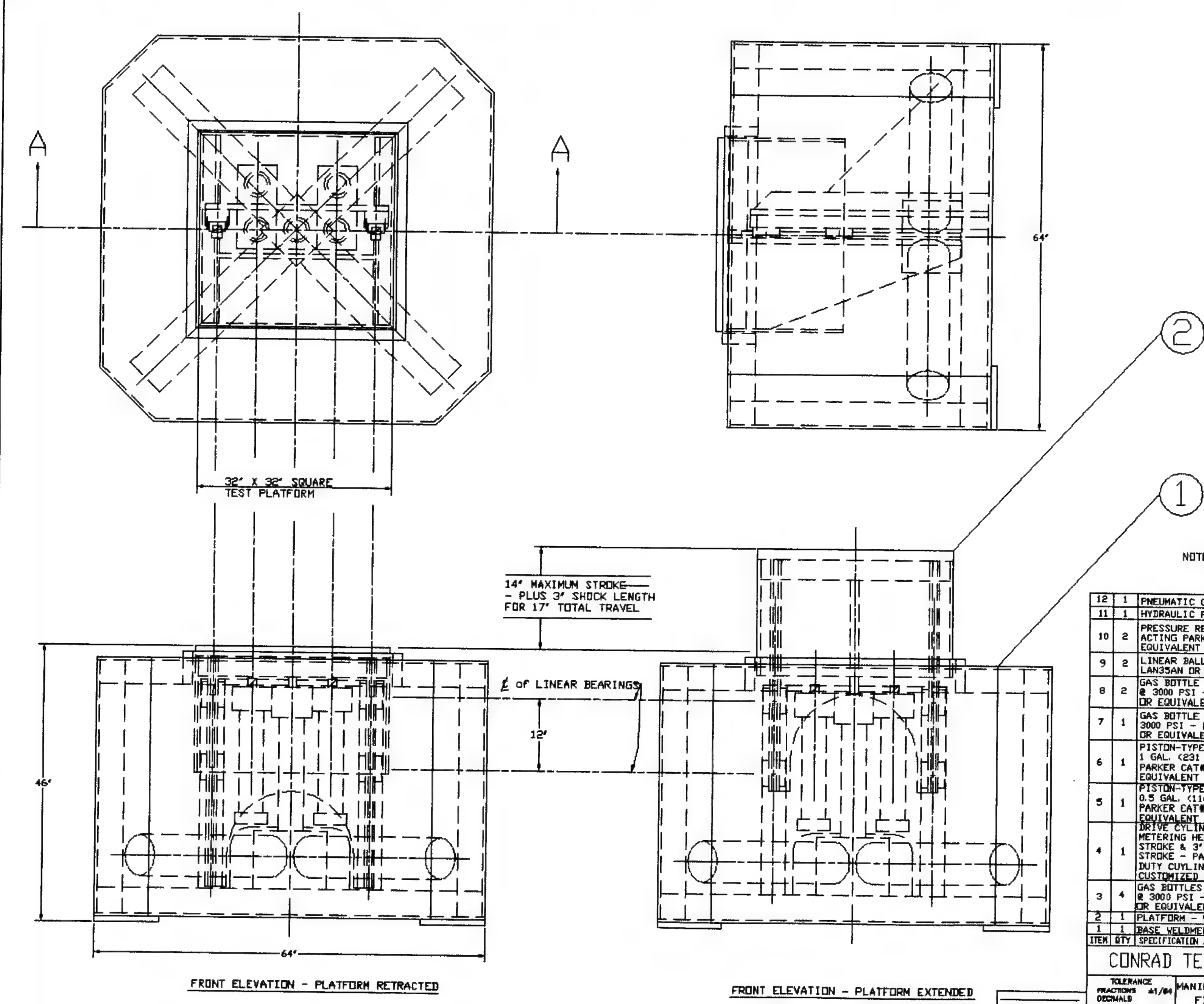
APPENDIX “A”

Design Layouts

Drawing # 96-C-0028-10 Sheet 1 of 2
Drawing # 96-C-0028-10 Sheet 2 of 2



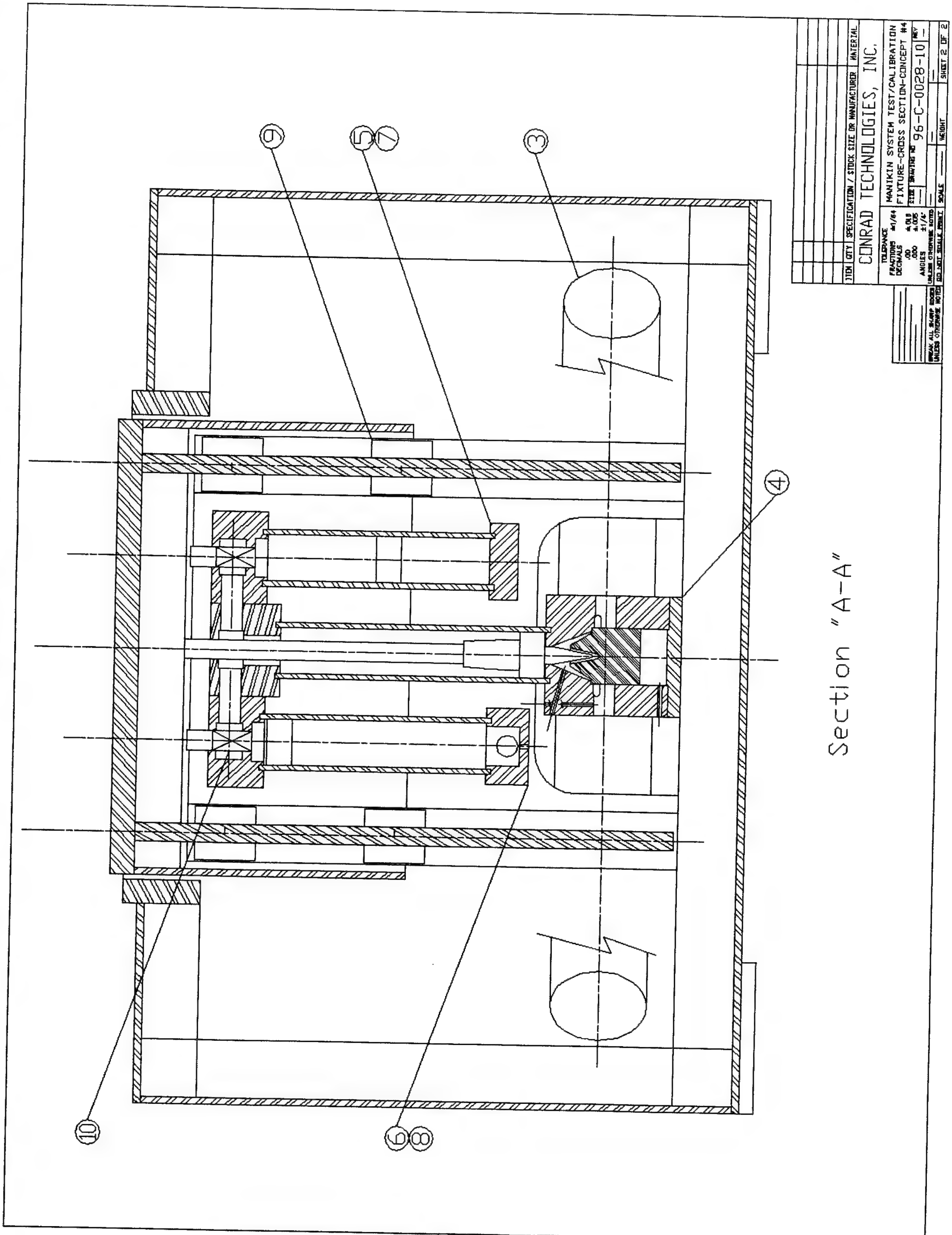
NOTE: SEE DRAWING 96-C-0028-10 SHEET 2 OF 2 FOR ITEMS 3 THROUGH 10

ITEM	QTY	SPECIFICATION / STOCK SIZE OR MANUFACTURER	MATERIAL
12	1	PNEUMATIC COMPRESSOR/SUPPLY	NOT SHOWN
11	1	HYDRAULIC POWER SUPPLY	NOT SHOWN
10	2	PRESSURE RELIEF VALVE - DIRECT ACTING PARKER SERIES RD163 OR EQUIVALENT	
9	2	LINEAR BALL SLIDE NSK MODEL NO. LAN35AN OR EQUIVALENT	
8	2	GAS BOTTLE - 1.5 GAL. (435 cu. in.) @ 3000 PSI - PARKER CAT # B6N0347D1 OR EQUIVALENT	
7	1	GAS BOTTLE - 1 GAL. (319 cu. in.) @ 3000 PSI - PARKER CAT# B6N0231D1 OR EQUIVALENT	
6	1	PISTON-TYPE ACCUMULATOR, GAS/OIL - 1 GAL. (231 cu. in.) @ 3000 PSI - PARKER CAT# A6NA0231D1 OR EQUIVALENT	
5	1	PISTON-TYPE ACCUMULATOR, GAS/OIL 0.5 GAL. (116 cu. in) @ 3000 PSI - PARKER CAT# A4NA0116D1 OR EQUIVALENT	
4	1	DRIVE CYLINDER & VALVE WITH METERING HEAD - 3.25 DIA. X 14" MAX STROKE & 3" CUSHION FOR TOTAL 17" STROKE - PARKER SERIES VH HEAVY DUTY CUYLINDER FOR 3000 PSI WITH CUSTOMIZED VALVE & CUSHION	
3	4	GAS BOTTLES - 2.5 GAL. (666 cu. in.) @ 3000 PSI - PARKER CAT# BN05780 OR EQUIVALENT	
2	1	PLATFORM - WELDMENT	STEEL
1	1	BASE WELDMENT	STEEL

CONRAD TECHNOLOGIES, INC.

TOLERANCE FRACTIONS ±1/64 DECIMALS .00 ±.010 .000 ±.005 ANGLES ±1/4°	MANIKIN SYSTEMS TEST/CALIBRATION FIXTURE-ASSEMBLY-CONCEPT #4	
UNLESS OTHERWISE NOTED	SIZE — DRAWING NO 96-C-0028-10	REV —
DO NOT SCALE PRINT	SCALE — WEIGHT —	SHEET 1 OF 2

BREAK ALL SHARP EDGES UNLESS OTHERWISE NOTED


Section "A-A"
3
4
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10
ITEM
QTY
SPECIFICATION / STOCK SIZE OR MANUFACTURER
MATERIAL
CONRAD TECHNOLOGIES, INC.
TOLERANCE
FRACTIONS ±1/64
DECIMALS
.00 ±.010
.000 ±.005
ANGLES ±1/4°
UNLESS OTHERWISE NOTED
MANIKIN SYSTEM TEST/CALIBRATION FIXTURE-CROSS SECTION-CONCEPT #4
SIZE
DRAWING NO
96-C-0028-10
REV
BREAK ALL SHARP EDGES UNLESS OTHERWISE NOTED
DO NOT SCALE PRINT
SCALE
WEIGHT
SHEET 2 OF 2

APPENDIX “B”

Ejection Data

TOWER TEST CATAPULT ACCELERATIONS (Ejection Seat)						
Input File - CATA_ACC.INP						
Output File - CATA_ACC.DAT						
Payload = 400 lbs						
Platform = 200 lbs						
Brake Force = 75 %						
Test Time = 0.12 sec						
TIME (sec)	**POS (in)**	**VEL (in/s)**	**ACC (g)**	**HP (hp)**	**P-WORK (ft-lb)**	**B-WORK (ft-lb)**
0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.017	0.00000	0.01122	0.05810	0.00108	0.0002	0.0000
0.018	0.00003	0.03367	0.05810	0.00324	0.00138	0.0000
0.019	0.00007	0.05612	0.05810	0.0054	0.00376	0.0000
0.02	0.00014	0.08982	0.11630	0.00911	0.00764	0.0000
0.021	0.00026	0.15721	0.23250	0.01761	0.01474	0.0000
0.022	0.00047	0.25829	0.29070	0.03031	0.02778	0.0000
0.023	0.00078	0.37062	0.29070	0.04349	0.04808	0.0000
0.024	0.00122	0.50541	0.40700	0.06465	0.07756	0.0000
0.025	0.00180	0.6739	0.46510	0.08976	0.11989	0.0000
0.026	0.00257	0.86484	0.52320	0.11976	0.17738	0.0000
0.027	0.00354	1.07825	0.58140	0.15501	0.25283	0.0000
0.028	0.00474	1.31415	0.63960	0.19588	0.34924	0.0000
0.029	0.00618	1.57251	0.69770	0.2427	0.46977	0.0000
0.03	0.00789	1.86457	0.81400	0.30749	0.62096	0.0000
0.031	0.00992	2.20155	0.93020	0.38631	0.81166	0.0000
0.032	0.01230	2.56098	0.93020	0.44938	1.04148	0.0000
0.033	0.01504	2.92041	0.93020	0.51245	1.30598	0.0000
0.034	0.01815	3.30231	1.04650	0.61438	1.61602	0.0000
0.035	0.02167	3.74037	1.22090	0.75518	1.99295	0.0000
0.036	0.02565	4.2346	1.33720	0.89974	2.4483	0.0000

TIME	POS	VEL	ACC	HP	P-WORK	B-WORK
(sec)	(in)	(in/s)	(g)	(hp)	(ft-lb)	(ft-lb)
0.037	0.03015	4.77376	1.45350	1.06477	2.98887	0.0000
0.038	0.03522	5.36909	1.62790	1.28267	3.63504	0.0000
0.039	0.04091	6.02058	1.74420	1.50197	4.40134	0.0000
0.04	0.04727	6.717	1.86050	1.74673	5.29538	0.0000
0.041	0.05435	7.44712	1.91860	1.97593	6.31951	0.0000
0.042	0.06219	8.23339	2.15110	2.35857	7.51338	0.0000
0.043	0.07085	9.12074	2.44180	2.8538	8.94937	0.0000
0.044	0.08046	10.12041	2.73250	3.43404	10.6814	0.0000
0.045	0.09112	11.1875	2.79070	3.85531	12.68665	0.0000
0.046	0.10285	12.29952	2.96510	4.43353	14.96848	0.0000
0.047	0.11575	13.51262	3.31390	5.29928	17.65038	0.0000
0.048	0.12992	14.83805	3.54650	6.13283	20.79821	0.0000
0.049	0.14545	16.24211	3.72090	6.97067	24.40509	0.0000
0.05	0.16242	17.71356	3.89530	7.88302	28.49375	0.0000
0.051	0.18091	19.27487	4.18600	9.08722	33.16784	0.0000
0.052	0.20101	20.95974	4.53490	10.54637	38.57668	0.0000
0.053	0.22286	22.74572	4.70930	11.80565	44.72882	0.0000
0.054	0.24655	24.65525	5.17440	13.83922	51.79682	0.0000
0.055	0.27223	26.73327	5.58140	15.99476	60.01603	0.0000
0.056	0.30004	28.88993	5.58140	17.2851	69.16799	0.0000
0.057	0.33004	31.13644	6.04650	19.94572	79.42751	0.0000
0.058	0.36238	33.58583	6.63150	23.30093	91.34873	0.0000
0.059	0.39730	36.30548	7.44540	27.87403	105.46381	0.0000
0.06	0.43507	39.27226	7.91060	31.81267	121.90353	0.0000
0.061	0.47591	42.44122	8.49190	36.62252	140.75851	0.0000
0.062	0.52005	45.87976	9.30590	42.98474	162.70393	0.0000
0.063	0.56778	49.64405	10.17800	50.44738	188.45929	0.0000
0.064	0.61948	53.84634	11.57299	61.54632	219.36208	0.0000
0.065	0.67566	58.62147	13.14300	75.37122	257.13837	0.0000
0.066	0.73690	63.93659	14.36800	89.32523	302.53381	0.0000
0.067	0.80365	69.58943	14.89100	100.53142	354.79373	0.0000
0.068	0.87612	75.34332	14.89100	108.84369	412.37189	0.0000
0.069	0.95434	81.1084	14.94900	117.5998	474.65091	0.0000
0.07	1.03837	86.99694	15.53000	130.73268	543.02051	0.0000
0.071	1.12842	93.14379	16.28599	146.37117	619.33478	0.0000
0.072	1.22474	99.52654	16.75100	160.60869	703.82813	0.0000
0.073	1.32751	106.0217	16.86800	172.21783	795.37579	0.0000
0.074	1.43680	112.5731	17.04200	184.64043	893.5448	0.0000
0.075	1.55267	119.1582	17.04200	195.44107	998.06726	0.0000
0.076	1.67511	125.732	16.98400	205.56036	1108.32959	0.0000
0.077	1.80412	132.2834	16.92600	215.57385	1224.12769	0.0000
0.078	1.93967	138.8124	16.86800	225.48183	1345.40308	0.0000
0.079	2.08175	145.3302	16.86800	236.06909	1472.32935	0.0000
0.08	2.23035	151.904	17.15800	250.75214	1606.28845	0.0000
0.081	2.38558	158.5451	17.21600	262.55063	1747.46399	0.0000
0.082	2.54744	165.1637	17.04200	270.89856	1894.10693	0.0000
0.083	2.71588	171.7264	16.92600	279.85153	2045.52429	0.0000
0.084	2.89087	178.2439	16.80900	288.57697	2201.80078	0.0000

TIME	POS	VEL	ACC	HP	P-WORK	B-WORK
(sec)	(in)	(in/s)	(g)	(hp)	(ft-lb)	(ft-lb)
0.085	3.07236	184.7277	16.75100	298.10019	2363.11597	0.0000
0.086	3.26030	191.1329	16.40200	302.37228	2528.1106	0.0000
0.087	3.45457	197.3808	15.93700	303.9126	2694.65015	0.0000
0.088	3.65503	203.5164	15.82100	311.21362	2863.76074	0.0000
0.089	3.86160	209.6297	15.82100	320.56186	3037.49878	0.0000
0.09	4.07428	215.7093	15.64700	326.44659	3215.34717	0.0000
0.091	4.29298	221.6879	15.29800	328.46082	3395.28223	0.0000
0.092	4.51761	227.554	15.06500	332.33228	3576.88647	0.0000
0.093	4.74807	233.3527	14.94900	338.34021	3761.26367	0.0000
0.094	4.98431	239.1178	14.89100	345.43823	3949.27271	0.0000
0.095	5.22630	244.8605	14.83300	352.44324	4141.15967	0.0000
0.096	5.47401	250.5581	14.65800	356.65808	4336.06689	0.0000
0.097	5.72738	256.1545	14.30900	356.49731	4531.98877	0.0000
0.098	5.98628	261.6155	13.95700	355.7258	4727.64648	0.0000
0.099	6.25059	267.0085	13.95700	363.05878	4925.31201	0.0000
0.1	6.52028	272.3679	13.78300	366.03772	5125.70752	0.0000
0.101	6.79531	277.6936	13.78300	373.19498	5328.99707	0.0000
0.102	7.07567	283.0306	13.84100	381.85974	5536.67383	0.0000
0.103	7.36139	288.4012	13.95700	392.14697	5749.6001	0.0000
0.104	7.65250	293.851	14.25100	407.41098	5969.67188	0.0000
0.105	7.94911	299.3687	14.30900	416.63965	6196.3252	0.0000
0.106	8.25123	304.8641	14.13500	419.46533	6426.13525	0.0000
0.107	8.55883	310.3371	14.19300	428.63196	6659.40332	0.0000
0.108	8.87194	315.9223	14.71600	451.36673	6901.7749	0.0000
0.109	9.19074	321.6872	15.12300	471.50577	7155.85986	0.0000
0.11	9.51537	327.6094	15.53000	492.30756	7421.20752	0.0000
0.111	9.84598	333.6102	15.53000	501.3251	7694.45703	0.0000
0.112	10.18259	339.5998	15.47200	508.53522	7972.12451	0.0000
0.113	10.52520	345.6343	15.76300	526.71527	8257.04492	0.0000
0.114	10.87388	351.7476	15.87910	539.74396	8550.41406	0.0000
0.115	11.22869	357.8721	15.82100	547.25146	8849.28809	0.0000
0.116	11.58962	363.9853	15.82100	556.59967	9152.84863	0.0000
0.117	11.95668	370.1548	16.11200	575.82617	9464.51074	0.0000
0.118	12.32997	376.4479	16.46100	597.55957	9787.48926	0.0000
0.119	12.70960	382.797	16.40200	605.58484	10118.3027	0.0000
0.12	13.09553	389.0449	15.93700	599.02307	10449.1582	0.0000
0.121	13.48231	383.3254	-18.21600	-599.93915	10482.0859	-299.4234
0.122	13.86212	376.2868	-18.21600	-588.92297	10482.0859	-626.3608
0.123	14.23489	369.2481	-18.21600	-577.90686	10482.0859	-947.2390
0.124	14.60062	362.2095	-18.21600	-566.89075	10482.0859	-1262.0579
0.125	14.95931	355.1708	-18.21600	-555.87457	10482.0859	-1570.8184
0.126	15.31096	348.1321	-18.21600	-544.8584	10482.0859	-1873.5198
0.127	15.65557	341.0935	-18.21600	-533.84229	10482.0859	-2170.1626
0.128	15.99314	334.0548	-18.21600	-522.82611	10482.0859	-2460.7461
0.129	16.32368	327.0161	-18.21600	-511.80997	10482.0859	-2745.2705
0.13	16.64718	319.9775	-18.21600	-500.79382	10482.0859	-3023.7373
0.131	16.96363	312.9388	-18.21600	-489.77768	10482.0859	-3296.1443
0.132	17.27305	305.9002	-18.21600	-478.76157	10482.0859	-3562.4927

TIME	POS	VEL	ACC	HP	P-WORK	B-WORK
(sec)	(in)	(in/s)	(g)	(hp)	(ft-lb)	(ft-lb)
0.133	17.57544	298.8615	-18.21600	-467.74542	10482.0859	-3822.7830
0.134	17.87078	291.8229	-18.21600	-456.72928	10482.0859	-4077.0129
0.135	18.15908	284.7842	-18.21600	-445.7131	10482.0859	-4325.1846
0.136	18.44035	277.7455	-18.21600	-434.69696	10482.0859	-4567.2979
0.137	18.71457	270.7069	-18.21600	-423.68082	10482.0859	-4803.3511
0.138	18.98176	263.6682	-18.21600	-412.66467	10482.0859	-5033.3462
0.139	19.24191	256.6295	-18.21600	-401.6485	10482.0859	-5257.2827
0.14	19.49502	249.5909	-18.21600	-390.63239	10482.0859	-5475.1602
0.141	19.74109	242.5522	-18.21600	-379.61624	10482.0859	-5686.9780
0.142	19.98012	235.5136	-18.21600	-368.6001	10482.0859	-5892.7373
0.143	20.21212	228.4749	-18.21600	-357.58395	10482.0859	-6092.4380
0.144	20.43707	221.4362	-18.21600	-346.56781	10482.0859	-6286.0806
0.145	20.65499	214.3976	-18.21600	-335.55164	10482.0859	-6473.6626
0.146	20.86587	207.3589	-18.21600	-324.53552	10482.0859	-6655.1875
0.147	21.06971	200.3202	-18.21600	-313.51938	10482.0859	-6830.6523
0.148	21.26651	193.2816	-18.21600	-302.5032	10482.0859	-7000.0601
0.149	21.45627	186.2429	-18.21600	-291.48709	10482.0859	-7163.4072
0.15	21.63899	179.2043	-18.21600	-280.47095	10482.0859	-7320.6958
0.151	21.81468	172.1656	-18.21600	-269.45477	10482.0859	-7471.9248
0.152	21.98332	165.1269	-18.21600	-258.43863	10482.0859	-7617.0957
0.153	22.14493	158.0883	-18.21600	-247.4225	10482.0859	-7756.2070
0.154	22.29950	151.0496	-18.21600	-236.40636	10482.0859	-7889.2607
0.155	22.44703	144.0109	-18.21600	-225.3902	10482.0859	-8016.2539
0.156	22.58752	136.9723	-18.21600	-214.37405	10482.0859	-8137.1890
0.157	22.72098	129.9336	-18.21600	-203.35793	10482.0859	-8252.0664
0.158	22.84739	122.895	-18.21600	-192.34178	10482.0859	-8360.8838
0.159	22.96677	115.8563	-18.21600	-181.32562	10482.0859	-8463.6416
0.16	23.07910	108.8176	-18.21600	-170.30948	10482.0859	-8560.3418
0.161	23.18440	101.779	-18.21600	-159.29333	10482.0859	-8650.9815
0.162	23.28266	94.74031	-18.21600	-148.27719	10482.0859	-8735.5645
0.163	23.37388	87.70164	-18.21600	-137.26105	10482.0859	-8814.0869
0.164	23.45807	80.66299	-18.21600	-126.2449	10482.0859	-8886.5508
0.165	23.53521	73.62432	-18.21600	-115.22875	10482.0859	-8952.9561
0.166	23.60531	66.58566	-18.21600	-104.21261	10482.0859	-9013.3018
0.167	23.66838	59.547	-18.21600	-93.19646	10482.0859	-9067.5898
0.168	23.72441	52.50834	-18.21600	-82.18031	10482.0859	-9115.8193
0.169	23.77340	45.46967	-18.21600	-71.16417	10482.0859	-9157.9883
0.17	23.81535	38.43101	-18.21600	-60.14803	10482.0859	-9194.0986
0.171	23.85026	31.39235	-18.21600	-49.13188	10482.0859	-9224.1504
0.172	23.87813	24.35369	-18.21600	-38.11573	10482.0859	-9248.1426
0.173	23.89897	17.31503	-18.21600	-27.09959	10482.0859	-9266.0781
0.174	23.91276	10.27636	-18.21600	-16.08344	10482.0859	-9277.9541
0.175	23.91952	3.2377	-18.21600	-5.0673	10482.0859	-9283.7695
0.175	23.92026	-0.28163	-18.21600	0.44077	10482.0791	-9284.4004

Pulse Stroke = 13.48 in						
Brake Stroke = 10.44 in						
Total Stroke = 23.92 in						
Maximum Pulse Horsepower = 605.58 hp						
Maximum Pulse Work = 10482.08 ft-lb						
Maximum Brake Work = 9284.40 ft-lb						
Maximum Pulse Acceleration = 17.2 g						
Maximum Brake Acceleration = 18.22 g						
Maximum Velocity = 389.04 in/s = 22.10 mph						

APPENDIX “C”

Crashworthy Seat Data

V-22 SEAT PAN ACCELERATION (Crashworthy Seat)						
Input File - V-22SP.INP						
Output File - V-22SP.DAT						
Payload = 400 lbs						
Platform = 200 lbs						
Brake Force = 75 %						
Test Time = 0.08 sec						
TIME	**POS**	**VEL**	**ACC**	**HP**	**P-WORK**	**B-WORK**
(sec)	**(in)**	**(in/s)**	**(g)**	**(hp)**	**(ft-lb)**	**(ft-lb)**
0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.011	0.0001	0.2576	1.3333	0.0546	0.0086	0.0000
0.012	0.0007	1.0304	2.6667	0.3435	0.1030	0.0000
0.013	0.0023	2.3184	4.0000	1.0538	0.4636	0.0000
0.014	0.0055	4.1216	5.3333	2.3730	1.3736	0.0000
0.015	0.0107	6.4400	6.6667	4.4885	3.2196	0.0000
0.016	0.0186	9.2736	8.0000	7.5875	6.4910	0.0000
0.017	0.0295	12.6224	9.3333	11.8574	11.7802	0.0000
0.018	0.0440	16.4864	10.6667	17.4856	19.7828	0.0000
0.019	0.0626	20.8656	12.0000	24.6593	31.2972	0.0000
0.02	0.0859	25.7600	13.3333	33.5661	47.2252	0.0000
0.021	0.1143	31.1696	14.6667	44.3931	68.5714	0.0000
0.022	0.1484	37.0944	16.0000	57.3277	96.4434	0.0000
0.023	0.1887	43.5344	17.3333	72.5573	132.0519	0.0000
0.024	0.2356	50.4896	18.6667	90.2693	176.7107	0.0000
0.025	0.2898	57.9600	20.0000	110.6509	231.8367	0.0000
0.026	0.3516	65.6328	19.7143	123.5942	296.2820	0.0000
0.027	0.4210	73.1952	19.4286	135.9339	367.6798	0.0000
0.028	0.4980	80.6472	19.1429	147.6786	445.7004	0.0000
0.029	0.5823	87.9888	18.8571	158.8369	530.0189	0.0000
0.03	0.6739	95.2200	18.5714	169.4174	620.3153	0.0000
0.031	0.7727	102.3408	18.2857	179.4287	716.2739	0.0000
0.032	0.8785	109.3512	18.0000	188.8794	817.5843	0.0000
0.033	0.9912	115.7912	15.3333	171.9324	917.0272	0.0000
0.034	1.1098	121.2008	12.6667	150.5829	1005.9042	0.0000
0.035	1.2333	125.5800	10.0000	125.5800	1081.9996	0.0000
0.036	1.3607	129.1542	8.5000	111.5423	1147.2778	0.0000

TIME (sec)	POS (in)	VEL (in/s)	ACC (g)	HP (hp)	P-WORK (ft-lb)	B-WORK (ft-lb)
0.037	1.4914	132.1488	7.0000	96.1082	1204.4406	0.0000
0.038	1.6249	135.0468	8.0000	110.4928	1261.2178	0.0000
0.039	1.7616	138.3312	9.0000	125.7557	1326.1432	0.0000
0.04	1.9017	142.0020	10.0000	142.0020	1399.7290	0.0000
0.041	2.0454	145.0932	6.0000	92.3321	1464.3325	0.0000
0.042	2.1914	146.6388	2.0000	39.9924	1500.8057	0.0000
0.043	2.3385	147.6048	3.0000	53.6744	1526.5502	0.0000
0.044	2.4867	148.9572	4.0000	67.7078	1559.9117	0.0000
0.045	2.6365	150.6960	5.0000	82.1978	1601.1124	0.0000
0.046	2.7884	153.3042	8.5000	132.3991	1660.0062	0.0000
0.047	2.9436	157.2648	12.0000	185.8584	1747.3473	0.0000
0.048	3.1029	161.1288	8.0000	131.8326	1834.9126	0.0000
0.049	3.2653	163.4472	4.0000	74.2943	1891.7203	0.0000
0.05	3.4293	164.2200	0.0000	14.9293	1916.3019	0.0000
0.051	3.5937	164.7030	2.5000	52.4054	1934.7998	0.0000
0.052	3.7590	166.1520	5.0000	90.6282	1974.0845	0.0000
0.053	3.9262	168.0840	5.0000	91.6822	2024.2200	0.0000
0.054	4.0952	170.0160	5.0000	92.7360	2074.9346	0.0000
0.055	4.2662	171.9480	5.0000	93.7898	2126.2290	0.0000
0.056	4.4391	173.8800	5.0000	94.8436	2178.1035	0.0000
0.057	4.6139	175.8120	5.0000	95.8975	2230.5571	0.0000
0.058	4.7907	177.7440	5.0000	96.9513	2283.5906	0.0000
0.059	4.9694	179.6760	5.0000	98.0051	2337.2039	0.0000
0.06	5.1501	181.6080	5.0000	99.0589	2391.3960	0.0000
0.061	5.3328	183.8684	6.7000	128.7078	2453.9807	0.0000
0.062	5.5180	186.7858	8.4000	159.6169	2533.2051	0.0000
0.063	5.7065	190.3600	10.1000	192.0906	2629.8452	0.0000
0.064	5.8990	194.5910	11.8000	226.4331	2744.8462	0.0000
0.065	6.0959	199.4790	13.5000	262.9495	2879.3193	0.0000
0.066	6.2981	205.0238	15.2000	301.9442	3034.5440	0.0000
0.067	6.5062	211.2255	16.9000	343.7216	3211.9673	0.0000
0.068	6.7208	218.0841	18.6000	388.5862	3413.2034	0.0000
0.069	6.9426	225.5996	20.3000	436.8428	3640.0332	0.0000
0.07	7.1722	233.7720	22.0000	488.7960	3894.4070	0.0000
0.071	7.4102	242.2342	21.8000	502.0854	4166.9209	0.0000
0.072	7.6567	250.6190	21.6000	514.9082	4446.6162	0.0000
0.073	7.9115	258.9266	21.4000	527.2688	4733.2358	0.0000
0.074	8.1745	267.1570	21.2000	539.1713	5026.5278	0.0000
0.075	8.4457	275.3100	21.0000	550.6199	5326.2407	0.0000
0.076	8.7251	283.3857	20.8000	561.6190	5632.1279	0.0000
0.077	9.0125	291.3842	20.6000	572.1726	5943.9404	0.0000
0.078	9.3078	299.3054	20.4000	582.2850	6261.4375	0.0000
0.079	9.6111	307.1494	20.2000	591.9606	6584.3745	0.0000
0.08	9.9221	314.9160	20.0000	601.2033	6912.5142	0.0000
0.081	10.2342	307.6903	-23.0000	-615.3807	6945.6211	-290.4458
0.082	10.5374	298.8031	-23.0000	-597.6063	6945.6211	-624.0181
0.083	10.8318	289.9159	-23.0000	-579.8319	6945.6211	-947.8132
0.084	11.1172	281.0287	-23.0000	-562.0574	6945.6211	-1261.8323

TIME (sec)	POS (in)	VEL (in/s)	ACC (g)	HP (hp)	P-WORK (ft-lb)	B-WORK (ft-lb)
0.085	11.3938	272.1415	-23.0000	-544.2831	6945.6211	-1566.0764
0.086	11.6615	263.2543	-23.0000	-526.5087	6945.6211	-1860.5435
0.087	11.9203	254.3671	-23.0000	-508.7342	6945.6211	-2145.2354
0.088	12.1703	245.4799	-23.0000	-490.9598	6945.6211	-2420.1514
0.089	12.4113	236.5927	-23.0000	-473.1854	6945.6211	-2685.2918
0.09	12.6434	227.7055	-23.0000	-455.4110	6945.6211	-2940.6558
0.091	12.8667	218.8183	-23.0000	-437.6366	6945.6211	-3186.2441
0.092	13.0811	209.9311	-23.0000	-419.8622	6945.6211	-3422.0562
0.093	13.2866	201.0439	-23.0000	-402.0878	6945.6211	-3648.0920
0.094	13.4832	192.1567	-23.0000	-384.3134	6945.6211	-3864.3533
0.095	13.6709	183.2695	-23.0000	-366.5390	6945.6211	-4070.8374
0.096	13.8497	174.3823	-23.0000	-348.7646	6945.6211	-4267.5464
0.097	14.0196	165.4951	-23.0000	-330.9902	6945.6211	-4454.4785
0.098	14.1807	156.6079	-23.0000	-313.2158	6945.6211	-4631.6348
0.099	14.3329	147.7207	-23.0000	-295.4414	6945.6211	-4799.0156
0.1	14.4761	138.8335	-23.0000	-277.6670	6945.6211	-4956.6211
0.101	14.6105	129.9463	-23.0000	-259.8926	6945.6211	-5104.4497
0.102	14.7360	121.0591	-23.0000	-242.1182	6945.6211	-5242.5024
0.103	14.8526	112.1719	-23.0000	-224.3438	6945.6211	-5370.7793
0.104	14.9604	103.2847	-23.0000	-206.5694	6945.6211	-5489.2798
0.105	15.0592	94.3975	-23.0000	-188.7950	6945.6211	-5598.0059
0.106	15.1492	85.5103	-23.0000	-171.0206	6945.6211	-5696.9546
0.107	15.2302	76.6231	-23.0000	-153.2462	6945.6211	-5786.1284
0.108	15.3024	67.7359	-23.0000	-135.4718	6945.6211	-5865.5254
0.109	15.3657	58.8487	-23.0000	-117.6974	6945.6211	-5935.1470
0.11	15.4201	49.9615	-23.0000	-99.9230	6945.6211	-5994.9922
0.111	15.4656	41.0743	-23.0000	-82.1486	6945.6211	-6045.0620
0.112	15.5023	32.1871	-23.0000	-64.3742	6945.6211	-6085.3565
0.113	15.5300	23.2999	-23.0000	-46.5998	6945.6211	-6115.8735
0.114	15.5489	14.4127	-23.0000	-28.8254	6945.6211	-6136.6162
0.115	15.5588	5.5255	-23.0000	-11.0510	6945.6211	-6147.5820
0.116	15.5605	-0.6955	-23.0000	1.3911	6945.6216	-6149.4697
Pulse Stroke = 9.92 in						
Brake Stroke = 5.64 in						
Total Stroke = 15.56 in						
Maximum Pulse Horsepower = 601.20 hp						
Maximum Pulse Work = 6949.19 ft-lb						
Maximum Brake Work = 6167.60 ft-lb						
Maximum Pulse Acceleration = 22.0 g						
Maximum Brake Acceleration = 23.0 g						
Maximum Velocity = 314.92 in/s = 17.89 mph						

APPENDIX "D"

Formulation of Computer Simulation for Drive Analysis

CALIBRATION SYSTEM COMPUTER MODEL

The development of a computer simulation of the manikin calibration apparatus has allowed for convenient dynamic analysis of various combinations of initial conditions. Utilizing identical pneumatic and hydraulic components, different combinations of chamber pressures, air/oil ratios, and valve and pipe sections were found to be capable of producing a wide range of acceleration profiles. The three acceleration profiles that have been described (calibration pulse, ejection test, crashworthy seat test) have all been approximated by the manikin calibration simulation. The primary controls that can be adjusted to achieve the desired results are the chamber pressures, the air and oil ratios, the valve and pipe configurations, and the valve control schedule.

Input to the computer simulation is accomplished through the use of an input file. The input file contains simulation run parameters, chamber and cylinder dimensions, valve and piping parameters, initial chamber pressures, air/oil distribution, and air and oil physical properties. These values are read into the program and used to generate the initial model setup. The initial setup routine computes the chamber volumes and initial air and oil volume in each chamber. The initial pressures on both sides of the piston are calculated assuming the system is in equilibrium. Initial air densities are calculated as functions of pressure and temperature in each of the chambers. Finally, the total mass of oil in the system is found from the chamber volumes and the specified oil fractions.

Hydraulic oil is treated as an incompressible fluid in the calibration system computer model. Density and viscosity values were obtained from fluid power handbooks and are treated as constants. The compressibility of the air portions of the actuation system required more complex treatment. A complex equation of state has been generated from experimental data obtained over a wide range of temperatures and pressures. Thermodynamic relations between pressure, density, and temperature can be found from the equation of state once it is properly formulated. Computer coding of the equation of state and the use of interpolating subroutines allows for convenient access of the air thermo-physical property data that is needed for computer modeling.

A simple integration routine is utilized to determine the dynamics of the piston and connected mass. At each time step, the piston position is updated from the previous velocity and the velocity is updated from the previous acceleration value. A frictional force opposing the direction of piston motion is computed as a function of velocity. Next, the forces acting on the piston are calculated and summed to determine the piston linear acceleration. The piston forces that are considered are: the propelling force present on the cap end, the resisting force present on the rod end, the friction force, and the weight of the payload.

The following contains an outline of the computer code that is the Calibration System Computer Model and the code itself. The outline and code given are representative of Concept “F”, which is that of a typical air and oil system.

Calibration System Computer Model - Concept "F"
(Typical Air & Oil Systems)

1. *Initialization of System*
   1.1. Compute metering pin base diameter, conical and cylindrical volumes of metering pin, total orifice area, cross-sectional area of piston rod and piston face with rod in place.
   1.2. Compute starting volumes according to initial position of pin.
   1.3. Compute starting pressures assuming system is in equilibrium.
   1.4. Compute initial air densities in the Charge Chamber, Drive Chamber, head and cap ends of Piston Chamber, Set Chamber, and Oil Reservoir.
   1.5. Compute total mass of the oil used in the system.

2. *Integration of System of Equations*
   2.1. Update Drive Piston position from previous velocity.
   2.2. Update Drive Piston velocity from previous acceleration.
   2.3. Compute velocity dependent frictional force of Drive Piston.
   2.4. Compute the forces acting on each side of the piston.
   2.5. Store old acceleration value to compute onset rate.
   2.6. Compute acceleration of the piston as a function of the force balance.
   2.7. Compute instantaneous acceleration onset rate.
   2.8. Store old Floating Set Piston velocity value to compute acceleration.
   2.9. Compute Floating Set Piston velocity from outlet flow rate of oil.
   2.10. Compute acceleration of Floating Set Piston from velocity.
   2.11. Update Floating Set Piston position.
   2.12. If the piston motion is driving it into the stops, perform the following:
      2.12.1. "Zero" the acceleration and the velocity.
      2.12.2. Assign the piston position to the extremity.

3. *Update Entire System*
   3.1. Store old volumes of chambers.
   3.2. Compute the change in volume of air on both the head and cap ends of the Piston Chamber as a function of the piston motion.
   3.3. Compute the current metering pin diameter in orifice.
   3.4. Compute volume of metering pin remaining in Drive Chamber A.
   3.5. Update air pressure in the Charger Chamber and Drive Chamber A due to piston movement.
   3.6. Set the pressure of air in Set Chamber equal to the oil pressure in Set Chamber.
   3.7. Limit the pressure in the rod end of the Piston Cylinder.
      3.7.1. Open relief valve when Set Chamber pressure exceeds relief valve limit.
      3.7.2. Compute mass of oil to add to the Reservoir.
   3.8. When necessary, compute the mass flow rate of air between the Charge Chamber and Drive Chamber A across the valve.
   3.9. Compute the total mass of air on the head end side of the piston (includes head end side of Piston Chamber and Reservoir).

3.10. Update the air density in the Charge Chamber and Drive Chamber A.
3.11. Update the air pressure in Charge Chamber at new density and constant temperature.
3.12. Update the air pressure in Drive Chamber A at new density and constant temperature.
3.13. In the metering pin section:
  3.13.1. Compute the annular orifice flow area.
  3.13.2. Compute the imaginary circular orifice diameter.
  3.13.3. Compute the diameter ratio.
  3.13.4. Calculate the flow coefficient alpha.
  3.13.5. Compute the average density across orifice.
  3.13.6. Check for choking conditions through orifice.
  3.13.7. Compute volumetric flow rate through opening
  3.13.8. Compute mass flow rate through opening
3.14. If Charge Chamber valve is open:
  3.14.1. Update mass in Charge Chamber and Drive Chamber A.
  3.14.2. Update air pressure in Charge Chamber, Drive Chamber A, and Reservoir at new density and temperature.
3.15. If Charge Chamber valve is closed:
  3.15.1. Update mass in Drive Chamber A.
  3.15.2. Update air pressure in Drive Chamber A and Reservoir at new density and temperature.
3.16. *Return to step 2.0.*

```
      PROGRAM calibair
      INCLUDE 'calibair.cmn'
c
c     August 1996
c
c     Conrad Technologies, Inc.
c     Station Square One, Suite 102
c     Paoli, PA 19301
c
c     ............................................
c     .                                          .
c     .   Actuator Program for Calibration SBIR. .
c     .   Used for Concepts E & F.               .
c     ............................................
c
c.....Initialize Variables and System
c
      iloop  = 0
      ier    = 0
      tclock = 0.0D0
      pi     = DACOS(-1.0d0)
      pi180  = pi / 1.80d2
      gravc  = 32.174
      ibrake = 0
c
c.....Command Line Arguments or Screen Entry
c
      CALL getnam
c
c.....Read Input from File
c
      CALL geninp
c
      CALL updsys(iloop,ier)
      CALL output(iloop)
c
      IF (ier.EQ.0) THEN
        done = .FALSE.
      ELSE
        done = .TRUE.
      END IF
c
c.....Integration Loop
c
      DO WHILE (.NOT.done)
c
        iloop = iloop + 1
        ier = 0
c
        IF (tclock.GE.tbegin) THEN
c
          tcltbg = tclock - tbegin
          CALL intg(ier)
          CALL updsys(iloop,ier)
c
        END IF
c
        tclock = tclock + dtloop
        IF (MOD(iloop,istep).EQ.0) CALL output(iloop)
        IF ( (ier.NE.0) .OR. (tclock.GE.tfinsh) ) done = .TRUE.
c
      END DO
c
c.....If last step was not output, dump it out.
c
      IF (MOD(iloop,istep).NE.0) CALL output(iloop)
```

```
c
c.....Close output files
c
      DO i = 1,nfout
        CLOSE(7+i)
      END DO
c
      WRITE(*,10) max_g,tmx_g
      WRITE(*,20) min_g,tmn_g
      WRITE(*,30) max_v*12.0D0,tmx_v
      WRITE(*,40) max_p*12.0D0,tmx_p
      WRITE(*,50) xp2/gravc,xp1*12.0D0,xp0*12.0D0
c
c.....End of Program
c
      STOP
   10 FORMAT (//' Maximum Acceleration [G] : ',F8.3,
     &          /' Occured at Time [sec] :     ',F8.6)
   20 FORMAT (//' Minimum Acceleration [G] : ',F8.3,
     &          /' Occured at Time [sec] :     ',F8.6)
   30 FORMAT (//' Maximum Velocity [in/sec] : ',F8.3,
     &          /' Occured at Time [sec] :     ',F8.6)
   40 FORMAT (//' Maximum Stroke [in] : ',F8.3,
     &          /' Occured at Time [sec] :     ',F8.6)
   50 FORMAT (//' Ending Acceleration [G] : ',F8.3,
     &          /' Ending Velocity [in/sec] : ',F8.3,
     &          /' Ending Position [in] : ',F8.3)
      END
c
c
C.....Thermodynamic constants and equation-of-state coefficients for AIR
      BLOCK DATA THMCON
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /ACOEF/ A
      COMMON /CONVRT/ TCON,PCON,VCON,RCON,GAMMA
      COMMON /CRIT/ R,TC,VC,PC,RC
      DIMENSION A(32)
      DATA A(1)/1.55623098409137D-01/,
     +     A(2)/1.25288666202326D+01/,   A(3)/-2.92541568638838D+02/,
     +     A(4)/4.29432480725523D+03/,   A(5)/-5.58450959675108D+05/,
     +     A(6)/3.92054480883008D-04/,   A(7)/-4.40985641881347D-02/,
     +     A(8)/5.86387178724129D-04/,   A(9)/7.97411385439405D+04/,
     +     A(10)/9.88045320906742D-09/,  A(11)/2.97999237261289D-04/,
     +     A(12)/-6.81783040959070D-02/, A(13)/2.02551630992042D-07/,
     +     A(14)/-1.62724281849497D-07/, A(15)/-1.06340143152999D-04/,
     +     A(16)/3.51428501875049D-10/,  A(17)/-1.70388092279449D-13/,
     +     A(18)/5.91103444646786D-11/,  A(19)/-1.05363473794348D-14/,
     +     A(20)/-7.32732651196979D+04/, A(21)/-5.42674649924748D+05/,
     +     A(22)/-4.48935466142735D-01/, A(23)/2.81453138446295D+02/,
     +     A(24)/-8.83132042791851D-07/, A(25)/-1.32229814838386D-05/,
     +     A(26)/-2.16521865046609D-12/, A(27)/-1.47835008246593D-09/,
     +     A(28)/-6.93219849301501D-19/, A(29)/6.06743598768355D-17/,
     +     A(30)/-3.20538718135891D-24/, A(31)/-4.73178337355130D-23/,
     +     A(32)/3.83950822306912D-22/,  GAMMA/5.97105475117183D-06/
      DATA TCON/1.8D0/, PCON/6894.8D0/, VCON/0.06243D0/, RCON/4.187D0/
      DATA R/2.870686D+02/, TC/132.50D0/, VC/2.913D-03/,
     +     PC/ 3.77D+06/, RC/343.3D0/
      END
c
c
c
      REAL*8 FUNCTION cmpflw(p1,p2,k)
      REAL*8 p1,p2,k,deltap
c
c.....Pressure Change in PSF to PSI
      deltap = DABS(p1-p2)/144.0D0
c
```

```
c.....Flow Rate in GPM to ft^3/s
      cmpflw = k*DSQRT(deltap) / 7.481D0 / 60.0D0
c
      RETURN
      END
c
c
c
      SUBROUTINE cmpfrc(Re,friction)
      REAL*8 Re,fl,fh,friction
c
c.....Compute Friction Based on Reynold's Number
c
      IF ((Re.LT.2000.0D0).AND.(Re.GT.0.0D0)) THEN
c
c.......Laminar Flow
        friction = 64.0D0 / Re
c
      ELSE IF ( (Re.GE.2000.0D0).AND.(Re.LT.4000.0D0) ) THEN
c
c.......Transitional Flow
c       (Linear Interpolation Between Laminar and Fully Turbulent)
        fl = 64.0D0 / 2000.0D0
        fh = 0.316D0/(4000.0D0**0.25)
        friction = (fh-fl)/2000.0D0*(Re-2000.0D0) + fl
c
      ELSE IF (Re.GE.4000.0D0) THEN
c
c.......Turbulent Flow - Blasius Equation
        friction = 0.316D0/(Re**0.25)
c
      ELSE
c
        friction = 0.0D0
c
      END IF
c
      RETURN
      END
c
c
c
      SUBROUTINE cmpprp(tmp,prs,spv,NOP)
c
c.....Control Computations of Air Properties
c
      REAL*8 atmp,tmp,prs,spv,P,V,U,H,S
      INTEGER NOP
c
C     IF NOP=1,  ENTER WITH T,V             (Compute P)
C     IF NOP=2,  ENTER WITH T,P, AND TRIAL V  (Compute V)
c
      atmp = ((tmp-32.0D0)/1.8D0)+273.15D0        ! F -> K
c
      IF (NOP.EQ.1) THEN
        V = spv * 0.06243D0                       ! ft3/lbm -> m3/kg
      ELSE
        V = spv * 0.06243D0                       ! ft3/lbm -> m3/kg
        P = (prs/144.0D0) * 6894.8D0              ! lbf/ft2 -> Pa
      END IF
c
      CALL PROP(atmp,P,V,U,H,S,NOP)
c
      IF (NOP.EQ.1) THEN
        prs = (P/6894.8D0) * 144.0D0              ! Pa   -> lbf/ft2
      ELSE
        spv = V / 0.06243D0                       ! m3/kg -> ft3/lbm
```

```
      END IF
c
      RETURN
      END
c
c
c
      SUBROUTINE denapx(P,spv)
      INCLUDE 'calibair.cmn'
c
      REAL*8 Rair,P,spv
c
      Rair = 1717.0D0
c
      spv = (Rair * (ambtmp + 460.0D0)) / (P * gravc)
c
      RETURN
      END
c
c
c
      SUBROUTINE exiter(iflg)
c
      IF (iflg.EQ.1) THEN
        PRINT *,'Too many valves are specified in input file.'
      END IF
c
      STOP 'Error Termination of Program.'
      END
c
c
c
      SUBROUTINE geninp
      INCLUDE 'calibair.cmn'
c
c.....General Input Routine
c
      OPEN(7,FILE=filinp,FORM='FORMATTED',ACCESS='SEQUENTIAL')
c
c.....Run Description for Output
      READ(7,100) rundsc
c
c.....Simulation Length [sec], Time Step [sec], Initiation of Flow [sec]
      READ(7,110) tfinsh,dtloop,tbegin
c
c.....Print Frequency, Valve flag
      READ(7,120) istep,ivalve
c
c.....Chamber Properties - Diameter [in], Length [in]
c     1)Charge Chamber  2)Cylinder  3)Oil Reservoir
c
      DO i = 1,nc
        READ(7,110) c_dia(i),c_len(i)
c
c.......Convert from [in] to [ft]
        c_dia(i) = c_dia(i) / 12.0D0
        c_len(i) = c_len(i) / 12.0D0
c
        c_area(i) = pi * c_dia(i) * c_dia(i) / 4.0D0
        c_vol(i) = c_area(i) * c_len(i)
      END DO
c
c.....Drive chamber A length and initial piston position settings
c
      READ(7,110) dcalen,xp0sav,xp0set
c.....Convert from [in] to [ft]
      dcalen = dcalen / 12.0D0
```

```
      xp0sav = xp0sav / 12.0D0
      xp0set = xp0set / 12.0D0
c
c.....Initial Charge Chamber Pressure, Resevoir Pressure
c     Ambient Temperature, Ambient Pressure
c     [psi] to [psf]
c
      READ(7,110) c_pres,r_pres,ambtmp,ambpres
      c_pres = c_pres * 144.0D0
      r_pres = r_pres * 144.0D0
      ambpres = ambpres * 144.0D0
c
C.....Air Properties - Specific gravity of air, Viscosity [lbm/(ft*sec)]
c
      READ(7,110) sg,visca
c
c.....Oil Properties - Density [lbm/ft^3], Viscosity [lbm/(ft*sec)]
c
      READ(7,110) denso,visco
c
c.....Piston Properties - Diameter, Rod Diameter, Length, Friction Coef.
c                         Weight of Piston/Load
      READ(7,110) p_dia,pr_dia,p_len,p_frct,p_mass
c
c.....Convert [in] to [ft] and [lbf] to [lbm]
      p_dia  = p_dia  / 12.0D0
      pr_dia = pr_dia / 12.0D0
      p_len  = p_len  / 12.0D0
      p_mass = p_mass / gravc
c
C.....Weight of piston
      weight = p_mass * gravc
c
C.....Read in oil relief valve set pressure, pressure opening range
      READ(7,130) setprs,dpopen
      setprs = setprs * 144.0D0
      dpopen = dpopen * 144.0D0
c
c.....Orifice Dimensions
c     Total Diameter, Initial Gap, Conical length, Cylindrical length
c      , Area Variation Power
      READ(7,110) O_dtot,O_dini,O_len1,O_len2,pwr
      O_dtot = O_dtot / 12.0D0
      O_dini = O_dini / 12.0D0
      O_len1 = O_len1 / 12.0D0
      O_len2 = O_len2 / 12.0D0
c
C.....Read in pneumatic valve properties
      IF (ivalve.EQ.1) READ(7,130) kfctr1,timv1,pwr1

  999 CLOSE(7)
c
      RETURN
c
  100 FORMAT(A)
  110 FORMAT(6F10.5)
  120 FORMAT(6I10)
  130 FORMAT(5F10.5,2F5.2)
c
      END
c
c
c
      SUBROUTINE GETARG(IARG,RTARG,STATUS)
c
c.....Retrieves command line argument IARG
c
```

```
      CHARACTER*(*) RTARG
      CHARACTER*40 CARG(12)
      INTEGER*2 IARG,STATUS
      COMMON/CMDARG/CARG
      STATUS = 0
      RTARG=CARG(IARG)
      RETURN
      END
c
c
c
      SUBROUTINE getnam
      INCLUDE 'calibair.cmn'
      CHARACTER uptrim*40,buffer*40
      INTEGER numarg,GNARGS
      LOGICAL okay
c
c.....Polls command line or user for input file name.
c
      okay = .FALSE.
c
c.....Find out how many arguments were present.
c
      numarg = GNARGS() - 1
c
      DO WHILE (.NOT.okay)
c
        IF (numarg.EQ.0) THEN
c
          WRITE(*,'(//1x,A,$)')'Enter Input Filename [6 char,No Ext.]: '
          READ(*,*) filnam
c
        ELSE
c
c.........Only use first argument
c
          CALL getarg(1,buffer,status)
          filnam = UPTRIM(buffer)
c
        END IF
c
c.......Check if file exists
c
        len = NBLANK(filnam)
        filinp = filnam(1:len)//'.INP'
        IF (len.GT.6) len=6
        DO ifl = 1,nfout
          WRITE(filout(ifl),'(A,I2.2,A)') filnam(1:len),ifl,'.DAT'
        END DO
        INQUIRE(FILE=filinp,EXIST=okay)
c
        IF (.NOT.okay) THEN
          IF (numarg.NE.0) THEN
            WRITE(*,'(/1x,A)') 'Error in Command Line Argument...'
            numarg = 0
          END IF
          WRITE(*,'(/1x,A/)') 'File does not exist. Please Re-enter:'
        END IF
c
      END DO
c
      RETURN
      END
c
c
c
      INTEGER FUNCTION GNARGS()
```

```
c
c.....Stores and counts command line arguments
c
      CHARACTER*127 CLINE
      CHARACTER*40 CARG(12)
      COMMON/CMDARG/CARG
C
      CALL GETCL(CLINE)
      NUMARG=0
      ION=0
      DO I=1,127
        IF ((CLINE(I:I).NE.' ').AND.(CLINE(I:I).NE.',').AND.
     +      (ION.EQ.0)) THEN
          NUMARG=NUMARG+1
          ION=1
          IMK=I
        ELSE IF (((CLINE(I:I).EQ.' ').OR.(CLINE(I:I).EQ.',')).AND.
     +           (ION.EQ.1)) THEN
          ION=0
          CARG(NUMARG)=CLINE(IMK:I-1)
        END IF
      END DO
      GNARGS=NUMARG+1
      RETURN
      END
c
c
c
      SUBROUTINE intg(ier)
      INCLUDE 'calibair.cmn'
      SAVE ionce,iflag
      DATA ionce/0/,iflag/0/
c
      REAL*8 ffrict,force3,force4,xp2old,arg1,arg2,xp1bold
c
      ier = 0
c
c.....Acceleration, Velocity, and Position of Drive Piston.
c
c.....Update Drive Piston Position
      xp0 = xp0 + dtloop * xp1
c
c.....Update Velocity & Velocity Dependent Frictional Force
      xp1 = xp1 + dtloop * xp2
c
c.....Friction force modelled as function of velocity
      ffrict = xp1 * p_frct
c
      force3 = press(3) * xacrp
      force4 = press(4) * xacr
      f_cap = force3
      f_rod = force4 + weight + ffrict
c
C.....Store old acceration value to compute onset rate
      xp2old = xp2

c.....Compute Acceleration Based on Pressure change across piston
      xp2 = (f_cap - f_rod) / p_mass

C.....Compute instantaneous acceleration onset rate
      xp2rte = (xp2 - xp2old) / dtloop

c
c.....Acceleration, Velocity, and Position of Brake Piston.
c
C.....Store old brake piston velocity value to compute acceleration
      xp1bold = xp1b
```

```
C.....Compute velocity of brake piston from outlet flow rate of oil
      xp1b = flwoil / xacr

C.....Compute acceleration from change in velocity
      xp2b = (xp1b - xp1bold) / dtloop

c.....Update Brake Piston Position
      xp0b = xp0b + dtloop * xp1b
c
      IF ((xp0.LE.0.0D0).AND.(xp1.LT.-1.0D-06)) THEN
        IF (iflag.EQ.0) WRITE(*,10) '...HIT BASE...  at Time = ',tclock
        iflag = 1
        xp0 = 0.0D0
        xp1 = 0.0D0
        xp2 = 0.0D0
      END IF
c
      arg1 = xp0 + 2.0D0 * p_len + vl4gap
      arg2 = c_len(2) - dcalen -xp0sav

      IF ( (arg1.GE.arg2).AND.(xp1.GT.0.0D0) ) THEN
        IF (ionce.EQ.0) WRITE(*,10) '...HIT WALL...  at Time = ',tclock
        ionce = 1
        xp0 = c_len(2) - dcalen - xp0sav - 2.0D0 * p_len - vl4gap
        xp1 = 0.0D0
        xp2 = 0.0D0
      END IF
c
      RETURN
   10 FORMAT(//5x,A,F10.6//)
      END
c
c
c
      SUBROUTINE output(iloop)
      INCLUDE 'calibair.cmn'
      REAL*8 cur_g
c
      IF (iloop.EQ.0) THEN
c
        DO i = 1,nfout
          OPEN(7+i,FILE=filout(i),FORM='FORMATTED')
          print *,'OPENING #',7+i,' : ',filout(i)
        END DO
c
        WRITE(8,100) 'Time','Accel','Veloc','Pos','Onset','Gap','Accelb'
     &                     ,'Velocb','Posb'
        WRITE(9,100) 'Time','Pr_1' ,'Pr_2' ,'Pr_3' ,'Pr_4' ,'Pr_5'
     &                     ,'Pr_6'
        WRITE(10,100)'Time','Vol_1','Vol_2','Vol_3','Vol_4','Vol_5'
     &                     ,'Vol_6'
        WRITE(11,100)'Time','F_Cap','F_Rod','Flwgpm'
        WRITE(12,100)'Time','Fmass_1','Fmass_2','Fmass_3','Fmass_4'
     &                     ,'Fmass_5','Fmass_6'
        WRITE(13,100)'Time','Flwrat','Orf_Dia','Orf_Area'
c
      END IF
c
      cur_g = xp2/gravc
      xp2rte = xp2rte/gravc
c
      IF (cur_g.GT.max_g) THEN
        max_g = cur_g
        tmx_g = tclock
      END IF
c
```

```
      IF (cur_g.LT.min_g) THEN
        min_g = cur_g
        tmn_g = tclock
      END IF
c
      IF (xp1.GT.max_v) THEN
        max_v = xp1
        tmx_v = tclock
      END IF
c
      IF (xp0.GT.max_p) THEN
        max_p = xp0
        tmx_p = tclock
      END IF
c
      WRITE(8,200) tclock,cur_g,xp1*12.0D0,xp0*12.0D0,xp2rte
     &             ,vl4gap*12.0D0,xp2b/gravc,xp1b*12.0D0,xp0b*12.0D0
      WRITE(9,200) tclock,(press(i)/144.0D0,i=1,nf)
      WRITE(10,200)tclock,(vol(i)*1728.0D0,i=1,nf)
      WRITE(11,200)tclock,f_cap,f_rod,flwgpm
      WRITE(12,200)tclock,(fmass(i),i=1,nf)
      WRITE(13,200)tclock,mflow,o_dia*12.0D0,o_area*144.0D0
c
      RETURN
c
  100 FORMAT(T6,A,T20,A,T34,A,T48,A,T62,A,T76,A,T90,A,T104,A,T118,A
     &       ,T132,A,T146,A,T160,A)
  110 FORMAT(T6,A,6x,10(4X,A,I2.2,9X,A,I2.2,5X))
  120 FORMAT(T6,A,T20,4(A,4X))
  200 FORMAT(21E14.6)
c
      END
c
c
c
      SUBROUTINE PGAS(T,P,V,U,H,S)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /ACOEF/ A
      COMMON /CONVRT/ TCON,PCON,VCON,RCON,GAMMA
      COMMON /CRIT/ R,TC,VC,PC,RC
      DIMENSION A(32)
C.....Pressure-density-temperature equation - solve for P(RHO,T)
      IF (REAL(T).EQ.REAL(TC)) THEN
         RHO=RC
      ELSE
         RHO=1.0D0/V
      END IF
      PL1=0.0D0
      DO I=3,5
         PTEMP=A(I)*  (T**(DBLE(3-I)))
         PL1=PTEMP+PL1
      END DO
      PL2=0.0D0
      DO I=6,9
         PTEMP=A(I)*  (T**(DBLE(7-I)))
         PL2=PTEMP+PL2
      END DO
      PL3=0.0D0
      DO I=10,12
         PTEMP=A(I)*  (T**(DBLE(11-I)))
         PL3=PTEMP+PL3
      END DO
      P1=RHO*R*T + (RHO**2.0D0) * (A(1)*T + A(2)*(T**(0.5D0)) +PL1) +
     +    (RHO**3.0D0) * PL2  +  (RHO**4.0D0) * PL3
      P2=(RHO**5.0D0) * A(13) +
     +    (RHO**6.0D0) * ((A(14)/T) + (A(15)/T**(2.0D0))) +
     +    (RHO**7.0D0) * (A(16)/T) +
```

```
     +    (RHO**8.0D0) * ((A(17)/T) + (A(18)/T**(2.0D0))) +
     +    (RHO**9.0D0) * (A(19)/T**(2.0D0))
      P3=(RHO**3.0D0) * ( (A(20)/T**(2.0D0)) + (A(21)/T**(3.0D0)) ) +
     +    (RHO**5.0D0) * ( (A(22)/T**(2.0D0)) + (A(23)/T**(4.0D0)) ) +
     +    (RHO**7.0D0) * ( (A(24)/T**(2.0D0)) + (A(25)/T**(3.0D0)) ) +
     +    (RHO**9.0D0) * ( (A(26)/T**(2.0D0)) + (A(27)/T**(4.0D0)) ) +
     +    (RHO**11.0D0) * ( (A(28)/T**(2.0D0)) + (A(29)/T**(3.0D0)) )+
     +    (RHO**13.0D0) * ( (A(30)/T**(2.0D0)) + (A(31)/T**(3.0D0)) +
     +                      (A(32)/T**(4.0D0)) )
      P4=DEXP(-GAMMA*(RHO**2.0D0))
      P=P1+P2+P3*P4
C.....End of pressure calculations
      RETURN
      END
C
C
C
      SUBROUTINE PROP(T,P,V,U,H,S,NOP)
C
C     ROUTINE FOR THERMODYNAMIC PROPERTIES EVALUATION
C
C     NOP DETERMINES THE TWO INPUT PROPERTIES. TRIAL VALUES FOR
C     T AND V MUST ALWAYS BE PROVIDED.
C     IF NOP=1,  ENTER WITH T,V
C     IF NOP=2,  ENTER WITH T,P, AND TRIAL V
C     IF NOP=3,  ENTER WITH P,V, AND TRIAL T
C     IF NOP=4,  ENTER WITH V,H, AND TRIAL T
C     IF NOP=5,  ENTER WITH T,H, AND TRIAL V
C     IF NOP=6,  ENTER WITH S,V, AND TRIAL T
C     IF NOP=7,  ENTER WITH S,T, AND TRIAL V
C     IF NOP=8,  ENTER WITH S,P, AND TRIAL T,V
C     IF NOP=9,  ENTER WITH H,P, AND TRIAL T,V
C     IF NOP=10, ENTER WITH S,H, AND TRIAL T,V
C
C     THE INTERNAL PARAMETERS ERP,ERH, AND ERS CONTROL THE
C     ACCCURACY OF P, H, AND S ITERATIONS.
C
C     THE USER MUST FILL THE COMMON BLOCK CRIT WITH THE GAS
C     CONSTANT R AND THE CRITICAL T,V,P.
C
C     PGAS(T,P,V,U,H,S) IS THE USER'S SUBSTANCE-SPECIFIC
C     ROUTINE THAT CALCULATES P,U,H,S FOR INPUT T,V.
C
C     ALL QUANTITIES ARE DOUBLE PRECISION.
C_______________________________________________________________
      IMPLICIT REAL*8 (A-H,O-Z)
      DATA ERP,ERH,ERS/3*0.000001D0/
      COMMON /CRIT/ R,TC,VC,PC,RC
C         INITIALIZATIONS
      DT=0.0D0
      KBR=0
      DVBF=1.0D0
      VMIN=0.0D0
      VMAX=1.0D30
      PMIN=1.0D30
      PMAX=0.0D0
      DVS1=2.0D0*VC
      DVS2=0.7D0*VC
      KTR=1
C         LOOP POINT
    1 RT=R*T
      CALL PGAS(T,PX,V,UX,HX,SX)
C         TEST FOR CONVERGENCE
      GO TO (10,20,20,40,40,60,60,80,90,100), NOP
   10 GO TO 700
   20 IF (DABS(P-PX).LT.(ERP*P)) GO TO 700
      GO TO 104
```

```
   40 IF (DABS(H-HX).LT.(ERH*RT)) GO TO 700
      GO TO 104
   60 IF (DABS(S-SX).LT.(ERS*R)) GO TO 700
      GO TO 104
   80 IF ((DABS(S-SX).LT.(ERS*R)).AND.(DABS(P-PX).LT.(ERP*P))) GO TO 700
      GO TO 104
   90 IF ((DABS(H-HX).LT.(ERH*RT)).AND.(DABS(P-PX).LT.(ERP*P)))
     +      GO TO 700
      GO TO 104
  100 IF ((DABS(S-SX).LT.(ERS*R)).AND.(DABS(H-HX).LT.(ERH*RT)))
     +      GO TO 700
      GO TO 104
  104 IF (KTR.GT.20) GO TO 850
C         CALCULATE THE NECESSARY PARTIAL DERIVATIVES
      IF (PX.LT.0.0D0) GO TO 300
      GO TO (880,120,110,110,120,110,120,110,110,110), NOP
C         PERTRUB T
  110 DT=0.001D0*T
      T1=T+DT
      V1=V
      CALL PGAS(T1,P1,V1,U1,H1,S1)
      GO TO (880,880,140,140,880,140,880,120,120,120), NOP
C         PERTURB V
  120 DV=0.001D0*V
      IF (V.LE.VC) DV=-DV
      V2=V+DV
      T2=T
      CALL PGAS(T2,P2,V2,U2,H2,S2)
  140 GO TO (880,220,230,240,250,260,270,280,290,296), NOP
  220 DPDV=(P2-PX)/DV
      IF (DPDV.GT.0.0D0) GO TO 300
C         THE POINT IS GOOD - UPDATE LIMITS
      IF ((PX.GT.P).AND.(V.GT.VMIN)) VMIN=V
      IF ((PX.LT.P).AND.(V.LT.VMAX)) VMAX=V
      IF (V.EQ.VMIN) PMIN=PX
      IF (V.EQ.VMAX) PMAX=PX
      IF (VMIN.GE.VMAX) GO TO 840
      IF ((VMIN.GT.0.0D0).AND.(VMAX.LT.1.0D30)) KBR=1
      DVBF=1.0D0
      IF (DPDV.EQ.0.0D0) GO TO 226
      DV=(P-PX)/DPDV
      DT=0.0D0
      GO TO 400
C         DPDV=0 AT A GOOD POINT - TREAT BY BRACKETING
  226 DVBF=0.5D0
      GO TO 300
  230 DPDT=(P1-PX)/DT
      DT=(P-PX)/DPDT
      DV=0.0D0
      GO TO 400
  240 DHDT=(H1-HX)/DT
      DT=(H-HX)/DHDT
      DV=0.0D0
      GO TO 400
  250 DHDV=(H2-HX)/DV
      DV=(H-HX)/DHDV
      DT=0.0D0
      GO TO 400
  260 DSDT=(S1-SX)/DT
      DT=(S-SX)/DSDT
      DV=0.0D0
      GO TO 400
  270 DSDV=(S2-SX)/DV
      DV=(S-SX)/DSDV
      DT=0.0D0
      GO TO 400
  280 DSDT=(S1-SX)/DT
```

```
      DSDV=(S2-SX)/DV
      DPDT=(P1-PX)/DT
      DPDV=(P2-PX)/DV
      DET=DSDT*DPDV-DPDT*DSDV
      DT=((S-SX)*DPDV-(P-PX)*DSDV)/DET
      DV=(DSDT*(P-PX)-DPDT*(S-SX))/DET
      GO TO 400
  290 DHDT=(H1-HX)/DT
      DHDV=(H2-HX)/DV
      DPDT=(P1-PX)/DT
      DPDV=(P2-PX)/DV
      DET=DHDT*DPDV-DPDT*DHDV
      DT=((H-HX)*DPDV-(P-PX)*DHDV)/DET
      DV=(DHDT*(P-PX)-DPDT*(H-HX))/DET
      GO TO 400
  296 DHDT=(H1-HX)/DT
      DHDV=(H2-HX)/DV
      DSDT=(S1-SX)/DT
      DSDV=(S2-SX)/DV
      DET=DHDT*DSDV-DSDT*DHDV
      DT=((H-HX)*DSDV-(S-SX)*DHDV)/DET
      DV=(DHDT*(S-SX)-DSDT*(H-HX))/DET
      GO TO 400
C         SPECIAL TREATMENT FOR NOP=2, DESIGNED TO AVOID BAD ROOTS
  300 IF (KBR.EQ.0) GO TO 320
C         CALCULATE SLOPE FROM BRACKETING VALUES
      DPDV=(PMAX-PMIN)/(VMAX-VMIN)
      V=VMAX
      PX=PMAX
      DV=DVBF*(P-PX)/DPDV
      DT=0.0D0
      DVBF=0.5D0*DVBF
      GO TO 400
C         NOT YET BRACKETED - ALTER V TO SEEK GOOD POINT
  320 IF (V.LE.VC) DV=-0.05D0*V
      IF (V.GT.VC) DV=0.2D0*V
      IF (VMIN.GT.0.0D0) DV=0.2D0*V
      IF (VMAX.LT.1.0D30) DV=-0.05D0*V
      GO TO 400
C         REGULATE THE MAXIMUM CHANGE
  400 DVM=0.2D0*V
      IF (V.LT.DVS1) DVM=0.5D0*DVM
      IF (V.LT.DVS2) DVM=0.5D0*DVM
      DTM=0.1D0*T
      IF (NOP.NE.2) GO TO 440
      VT=V+DV
      IF ((VT.GE.VMIN).AND.(VT.LE.VMAX)) GO TO 440
C         BRACKETING LIMITATION
      DV=VMIN+(P-PMIN)*(VMAX-VMIN)/(PMAX-PMIN) - V
  440 DVA=DABS(DV)
      DTA=DABS(DT)
      IF (DVA.GT.DVM) DV=DV*DVM/DVA
      IF (DTA.GT.DTM) DT=DT*DTM/DTA
      T=T+DT
      V=V+DV
      KTR=KTR+1
      GO TO 1
C         NORMAL RETURN
  700 GO TO (710,720,720,740,740,760,760,780,790,796), NOP
  710 P=PX
      U=UX
      H=HX
      S=SX
      RETURN
  720 U=UX
      H=HX
      S=SX
```

```
      RETURN
  740 P=PX
      U=UX
      S=SX
      RETURN
  760 P=PX
      U=UX
      H=HX
      RETURN
  780 H=HX
      U=UX
      RETURN
  790 S=SX
      U=UX
      RETURN
  796 P=PX
      U=UX
      RETURN
C       ERROR WRITES
  840 WRITE(6,842) T,P,V,VMIN,VMAX
  842 FORMAT ('PROP ERROR - T,P,V,VMIN,VMAX= ',5D15.5)
      RETURN
  880 WRITE(6,882)
  882 FORMAT ('PROGRAM ERROR IN PROP')
      RETURN
  850 WRITE (6,852) NOP,T,P,V,H,S,PX,HX,SX
  852 FORMAT ('PROP NOT CONVERGENT FOR NOP= ',I3/
     +  1H ,7X,'T',14X,'P',14X,'V',14X,'H',14X,'S',14X,'PX',13X,
     +  'HX',13X,'SX',/1H,8E15.5)
      RETURN
      END
c
c
c
      SUBROUTINE updsys(iflg,ier)
      INCLUDE 'calibair.cmn'
c
      INTEGER istrt
      REAL*8 deltap,spv,vloldc,vlnewc,oldvol(nf),arg
      REAL*8 tmparea,cnlen,stdden,flwfac
c
c.....Update Piston System
c
      ier = 0
c
c.....Standard Air Density at 1 atm and 60 degrees F [lbm/ft3]
      stdden = 0.076474D0
c
      IF (iflg.EQ.0) THEN
c
c.....Initial Setup
c
C.......Drive piston dynamics
        xp0    = 0.0D0
        xp1    = 0.0D0
        xp2    = 0.0D0

C.......Brake piston dynamics
        xp0b    = 0.0D0
        xp1b    = 0.0D0
        xp2b    = 0.0D0

C.......Compute metering pin base diameter
        cndia = o_dtot - 2.0D0 * o_dini
        cnarea = pi * cndia * cndia / 4.0D0

C.......Conical and cylindrical Volumes of Metering Pin
```

```
         cnvol = cnarea * o_len1 / 3.0D0
         cyvol = cnarea * o_len2

C.......Compute total orifice area
         o_atot =  pi * o_dtot * o_dtot  / 4.0D0

C.......Cross-sectional area of piston rod
         pr_area = pi * pr_dia*pr_dia / 4.0D0

C.......Cross-sectional area of piston face with rod in place
         xacr = c_area(2) - pr_area
c
C.......Cross-sectional area of piston face with metering pin in place
         xacrp = c_area(2) - cnarea
c
C.......Initial volume calculations of chambers
         vol(1) = c_vol(1)
         vl4gap = xp0set - p_len - xp0sav
         vol(4) = xacr * vl4gap
         arg = dcalen + xp0set + p_len + xp0b
         vol(5) = xacr * (c_len(2) - arg)
         vol(6) = c_vol(3)

C.......Compute initial volumes of drive chambers according to initial
c         position of pin
         IF (xp0sav.EQ.o_len2) THEN
            vol(2) = c_area(2) * dcalen - cnvol
            vol(3) = c_area(2) * xp0sav - cyvol
            cnlen  = o_len1
            tmparea = cnarea

         ELSE IF ((xp0sav.GT.o_len2).AND.(xp0sav.LT.(o_len1+o_len2)))
     &                                                              THEN

C.......Pin length remaining in drive chamber A
            cnlen = (o_len1 + o_len2) - xp0sav

C.......Compute current metering pin diameter
            tmpdia = (1.0D0 - (cnlen/o_len1)**pwr) * cndia

C.......Volume of metering pin remaining in drive chamber A
            tmparea = pi * tmpdia * tmpdia / 4.0D0
            tmpvol = tmparea * cnlen / 3.0D0

            vol(2) = c_area(2) * dcalen - tmpvol
            vol(3) = c_area(2) * (xp0 + xp0sav) - (cnvol - tmpvol) -cyvol

         ELSE IF (xp0sav.GE.(o_len1+o_len2)) THEN
            vol(2) = c_area(2) * dcalen
            vol(3) = c_area(2) * xp0sav - (cnvol + cyvol)
            cnlen  = 0.0D0
            tmparea = 0.0D0
         END IF

C.......Compute annular orifice flow area
         o_area = o_atot - tmparea

C.......Imaginary circular orifice diameter
         o_dia = DSQRT(4.0D0 * o_area / pi)

C.......Set initial pressures of chambers
         press(1) = c_pres
         press(4) = r_pres
         press(5) = press(4)
         press(6) = press(5)

C.......Assign chamber 3 pressure so piston is in equilibrium
```

```
         press(3) = (press(4) * xacr + weight) / xacrp

C.......Assign chamber 2 pressure accordingly
         IF (ivalve.EQ.0) THEN
            press(2) = press(1)
         ELSE
            press(2) = press(3)
         END IF
c
C.......Calculate density and mass in air filled compartments at given pressure
and temp.
         DO i = 1,4
           CALL denapx(press(i),spv)
           CALL cmpprp(ambtmp,press(i),spv,2)
           dens(i) = 1.0D0 / spv
           fmass(i) = dens(i) * vol(i)
         END DO

C.......Calculate density and mass in oil filled compartments
         dens(5) = denso
         fmass(5) = dens(5) * vol(5)

C.......No oil in oil reservoir initially
         fmass(6) = 0.0D0

       ELSE

C.......Store old volumes of chambers
         DO i=1,nf
            oldvol(i) = vol(i)
         END DO

C.......Update volumes of chambers from piston motion
         cnlen = (o_len1 + o_len2) - (xp0sav + xp0)

C.......Compute current metering pin diameter
         IF (cnlen.GT.0.0D0) THEN
           tmpdia = (1.0D0 - ((o_len1-cnlen)/o_len1)**pwr) * cndia
         ELSE
C.......If metering pin has been pulled past orifice - no pin diameter remains
           cnlen    = 0.0D0
           tmpdia   = 0.0D0
         END IF

C.......Volume of metering pin remaining in drive chamber A
         tmparea = pi * tmpdia * tmpdia / 4.0D0
         tmpvol = tmparea * cnlen / 3.0D0

         vol(1) = c_vol(1)
         vol(2) = c_area(2) * dcalen - tmpvol
         vol(3) = c_area(2) * (xp0 + xp0sav) - (cnvol - tmpvol) - cyvol
         vl4gap = (xp0set+xp0b) - (xp0sav+xp0+p_len)
         vol(4) = xacr * vl4gap
         arg = dcalen + xp0set + p_len + xp0b
         vol(5) = xacr * (c_len(2) - arg)

         IF (ivalve.EQ.0) THEN
C.......Update air pressure in charge chamber & drive chamber A
            vloldc = oldvol(1) + oldvol(2)
            vlnewc = vol(1) + vol(2)
            press(1) = press(1) * (vloldc / vlnewc)**1.4D0
            press(2) = press(1)
            dens(1) = fmass(1) / vol(1)
            dens(2) = fmass(2) / vol(2)
            istrt = 3
         ELSE
            istrt = 2
```

```
        END IF

C.......Update needed pressures and densities from change in volumes
        DO i=istrt,4
           press(i) = press(i) * (oldvol(i)/vol(i)) ** 1.4D0
           dens(i)  = fmass(i) / vol(i)
        END DO

C.......Pressures are equal across secondary piston
        press(5) = press(4)

C.......Limit pressure in rod end of cylinder
        IF ((press(5).GE.setprs).AND.(xp1.GE.0.0D0)) THEN
           IF (dpopen.GT.0.0D0) THEN
              flwfac = (press(5) - setprs) / dpopen
              IF (flwfac.GT.1.0D0) flwfac = 1.0D0
           ELSE
              flwfac = 1.0D0
           END IF
           flwoil = flwfac * (xacr * xp1)
           ibrake = 1
        ELSE
           flwoil = 0.0D0
           ibrake = 0
        END IF

C.......Add oil to reservoir
        fmass(6) = fmass(6) + denso * flwoil * dtloop

C.......Convert flow rate of oil leaving cylinder through relief valve
c.......(ft3/sec) -> GPM
        flwgpm = flwoil * (7.481D0 * 60.0D0)

C*******************ADDITION OF VALVE INTO SYSTEM************************

        IF (ivalve.EQ.1) THEN
C.......Compute Mass Flow between Charge Chamber and Drive Chamber A across valve
           CALL valve(press(1),press(2),sg,ambtmp,kfctr1,flwrat1,
     &                tcltbg,timv1,pwr1)
           IF (flwrat1.LT.0.0D0) flwrat1 = 0.0D0

C.......Convert air mass flow rate units from SCFM to lbm/sec
           mfr1 = flwrat1 * stdden / 60.0D0

C.......Update air densities in Charge Chamber and Drive Chamber A
           fmass(1) = fmass(1) - mfr1 * dtloop
           fmass(2) = fmass(2) + mfr1 * dtloop
           dens(1) = fmass(1) / vol(1)
           dens(2) = fmass(2) / vol(2)

C.......Update air pressure in Charge Chamber at new density and constant temp.
           spv = 1.0D0 / dens(1)
           CALL cmpprp(ambtmp,press(1),spv,1)

C.......Update air pressure in Drive Chamber A at new density and constant temp.
           spv = 1.0D0 / dens(2)
           CALL cmpprp(ambtmp,press(2),spv,1)
        END IF

C.......METERING PIN SECTION (ORIFICE BETWEEN CHAMBERS 2 AND 3)

C.......Compute annular orifice flow area
        o_area =  o_atot - tmparea

C.......Imaginary circular orifice diameter
        o_dia = DSQRT(4.0D0 * o_area / pi)
```

```
C.......Compute diameter ratio
        dratio = o_dia / c_dia(2)

C.......Calculate flow coefficient alpha
        Cd = 1.0D0
        alpha = Cd / DSQRT(1.0D0 - dratio**4.0D0)

C.......Compute average density across orifice
        denave = (dens(2) + dens(3)) / 2.0D0

C.......Check for choking conditions through orifice
        Pcrito = 0.53D0 * press(2)
        IF (press(3).LT.Pcrito) THEN
           deltaP = press(2) - Pcrito
        ELSE
           deltaP = press(2) - press(3)
        END IF

C.......Compute volumetric flow rate through opening
        arg = DSQRT(2.0D0 * DABS(deltaP) / denave)
        qflow = alpha * o_area * arg
        qflow = DSIGN(qflow,deltaP)

C.......Compute mass flow rate through opening
        mflow = denave * qflow

        IF (ivalve.EQ.0) THEN
C.......Update mass in chambers 1 and 2
           fmassu = fmass(1) + fmass(2)
           fmassu = fmassu - mflow * dtloop
           volu = vol(1) + vol(2)
           densu = fmassu / volu
           dens(1) = densu
           dens(2) = densu
           fmass(1) = dens(1) * vol(1)
           fmass(2) = dens(2) * vol(2)
           istrt = 1
        ELSE
C.......Update mass in chamber 2 only
           fmass(2) = fmass(2) - mflow * dtloop
           dens(2) = fmass(2) / vol(2)
           istrt = 2
        END IF

C.......Update mass and density in the other cylinder chambers
        fmass(3) = fmass(3) + mflow * dtloop
        dens(3) = fmass(3) / vol(3)
        fmass(5) = denso * vol(5)

C.......Update air pressure in chambers at new density and temp.
        DO i=istrt,3
           spv = 1.0D0 / dens(i)
           CALL cmpprp(ambtmp,press(i),spv,1)
        END DO
c
      END IF
c
      RETURN
  200 FORMAT(21E14.6)
      END
c
c
c
      CHARACTER*(*) FUNCTION uptrim(a)
c
c.....Converts lower case characters to upper case.  In addition,
c     it trims away leading and trailing blanks.
```

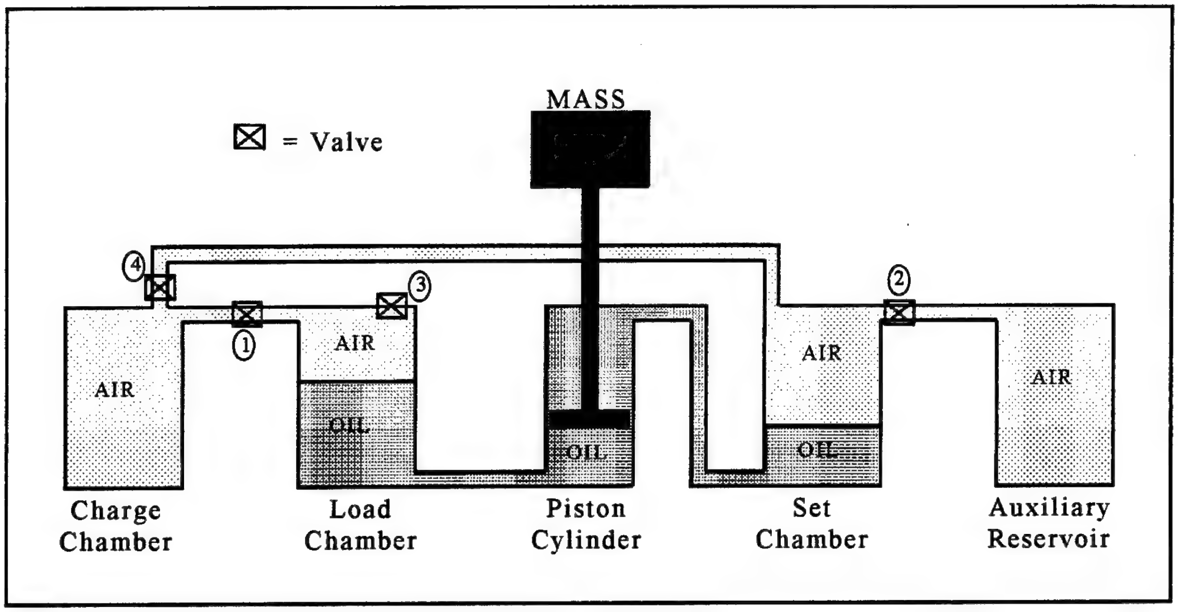
```
c
      character a*(*),tmp*1,space*1
      DATA space/' '/
      ilen=LEN(A)
      ilen1=LEN(UPTRIM)
      i=1
10    IF ((a(i:i).EQ.space).AND.(i.LE.ilen)) THEN
        i=i+1
        GO TO 10
      END IF
      IF (i.GT.ilen) THEN
        UPTRIM(1:ilen)=a
        RETURN
      END IF
      ista=i
      ishift=ista-1
      i=ilen
20    IF (a(i:i).EQ.space) THEN
        i=i-1
        GO TO 20
      END IF
      ifin=i
      DO 100 i=ista,ifin
        tmp=a(i:i)
        istng=ICHAR(tmp)
        IF ((istng.GE.97).AND.(istng.LE.122)) THEN
          istng=istng-32
          tmp=CHAR(istng)
        END IF
        j=i-ishift
        UPTRIM(j:j)=tmp
100   CONTINUE
      IF (j.LT.ilen1) THEN
        DO 200 i=j+1,ilen1
200     UPTRIM(i:i)=space
      END IF
      RETURN
      END
c
      SUBROUTINE valve(Pup,Pdwn,sg,temp,vcnst,Qrate,tcltbg,timv,pwr)
c
      REAL*8 Pup,Pdwn,sg,temp,vcnst,Qrate
      REAL*8 deltaP,Pcrit,tempR,dabsP,denom
      REAL*8 tcltbg,timv,perc,vc,pwr
c
c.....Convert degreesF temperature to Rankine
      tempR = temp + 460.0D0
c
c.....Compute critical pressure (53% of upstream pressure)
      Pcrit = 0.53D0 * Pup
c
c.....Compute change in pressure through valve.
      deltaP = Pup - Pdwn
      dabsP = DABS(deltaP)
c
c.....Calculate rate of flow based on downstream pressure with
c     respect to Critical pressure. (Standard Cubic feet per minute,
c     @ 1 atm and 60 degrees F)
c
      IF (tcltbg.LT.timv) THEN
        IF (pwr.LE.0.0D0) pwr = 1.0D0
        perc = (tcltbg**pwr)/(timv**pwr)
      ELSE
        perc = 1.0D0
      END IF
      vc = vcnst * perc
c
```

```
      IF (dabsP.EQ.0.0D0) THEN
c
        Qrate = 0.0D0
c
      ELSE
c
        IF (Pdwn.GT.Pcrit) THEN
c
          denom = DSQRT( (sg*tempR) / (dabsP*Pdwn) )
          Qrate = (vc * 22.48D0) / denom
c
        ELSE
c
          Qrate = vc * ((Pup/DSQRT(2.0D0*sg)) * DSQRT(520.0D0/tempR))
c
        END IF
c
      END IF
c
      Qrate = SIGN(Qrate,deltaP)
c
      RETURN
      END
```

APPENDIX "E"

Performance Analysis of Drive Concepts "A" Through "F"

Air/Oil Configuration (Concept "A")



<u>Concept Specifications</u>

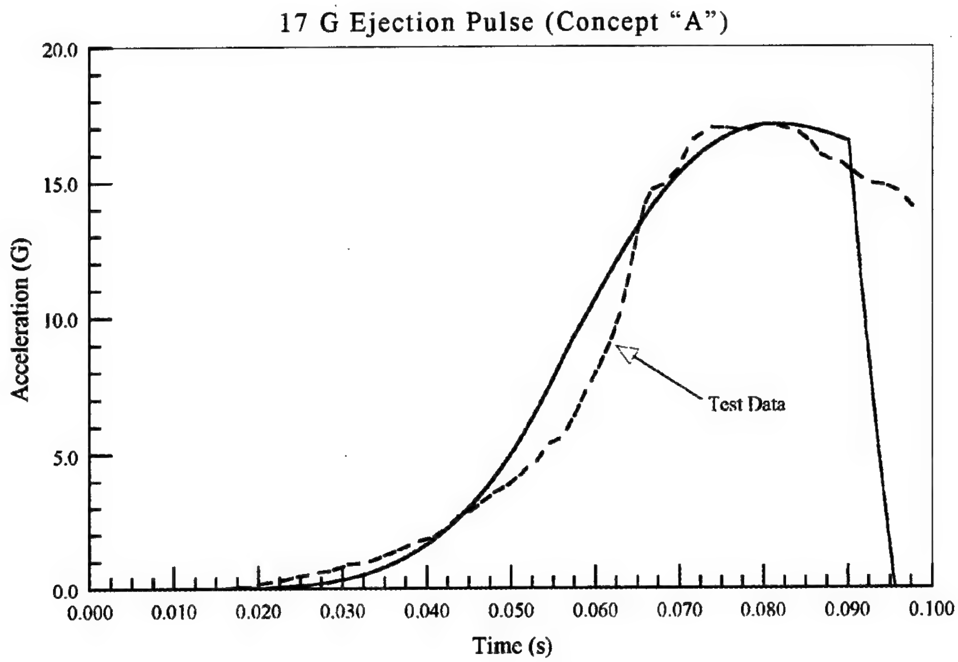
Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Set Chamber Volume:	325.0 in^3
Auxiliary Reservoir Volume:	20.0 in^3
Piston Diameter:	2.5 in
Rod Diameter:	1.0 in
Maximum Available Stroke:	14.5 in

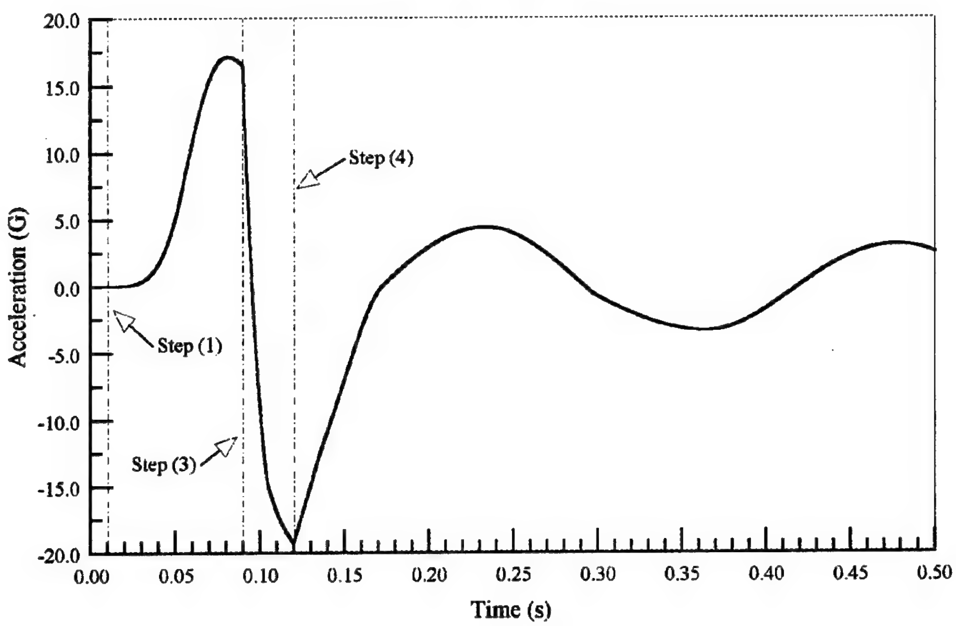
<u>Valve Description</u>

#1: Pneumatic valve used to charge load chamber.
#2: Pressure relief valve. (Only used for calibration pulse.)
#3: Load chamber pressure vent to ambient.
#4: Pneumatic valve used to charge set chamber.

<u>Sequencing Steps</u>

1. Valve #1 is opened; initiating acceleration.
2. Valve #2 provides pressure relief when necessary.
3. Valves #3 & #4 open and valve #1 closes; initiating braking.
4. Valves #3 & #4 close and valve #1 re-opens; bringing system to rest.

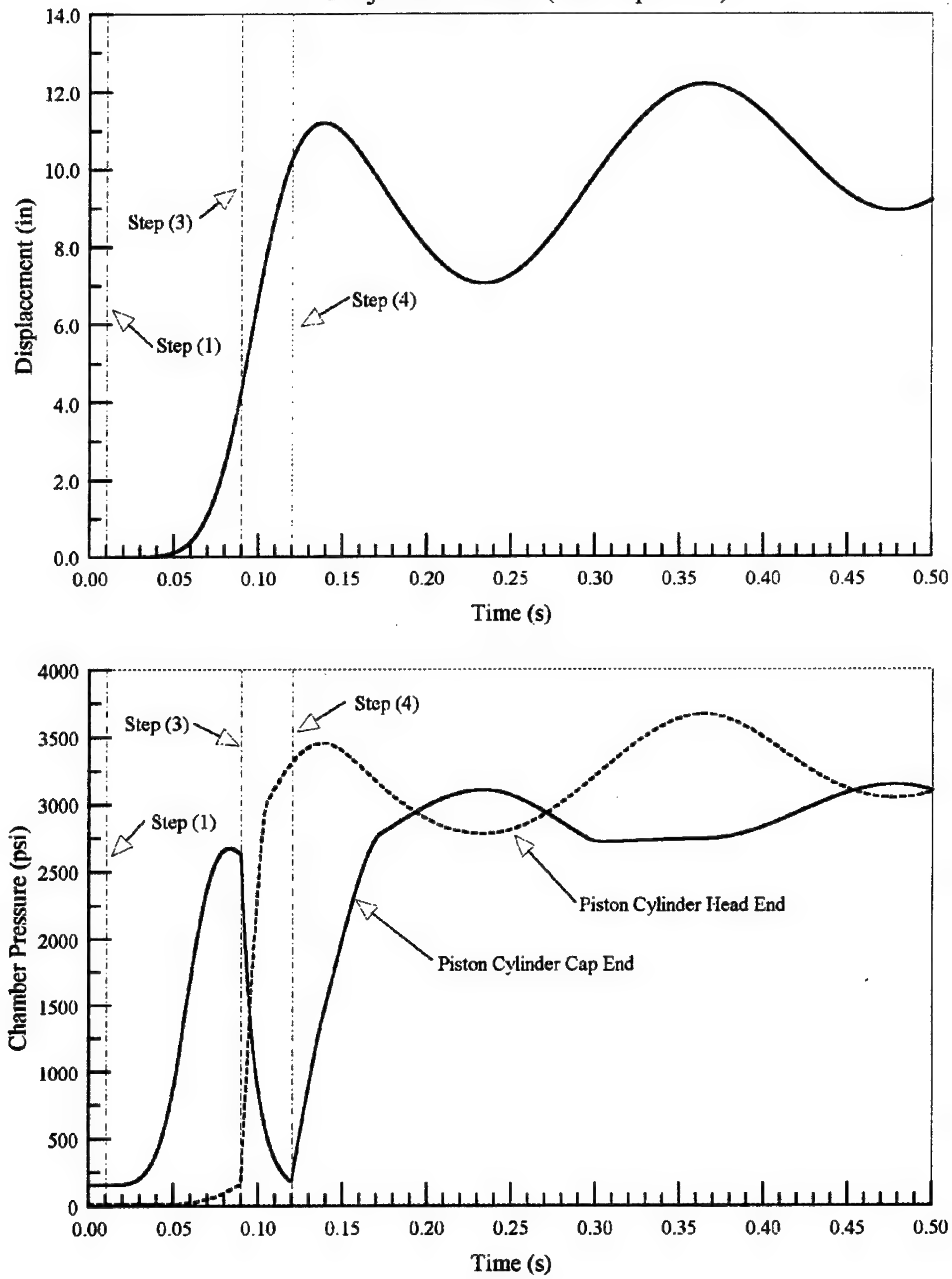




<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	3100.0 psi
Set Chamber Pressure:	14.7 psi
Load Chamber Air Fraction:	25.0% Air
Set Chamber Air Fraction:	40.0% Air

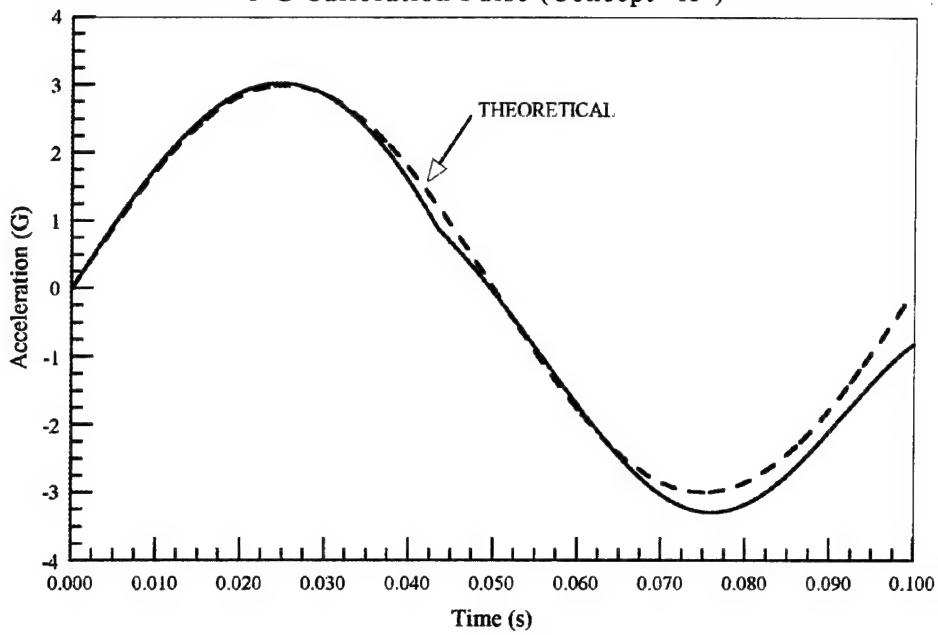
17 G Ejection Pulse (Concept "A")

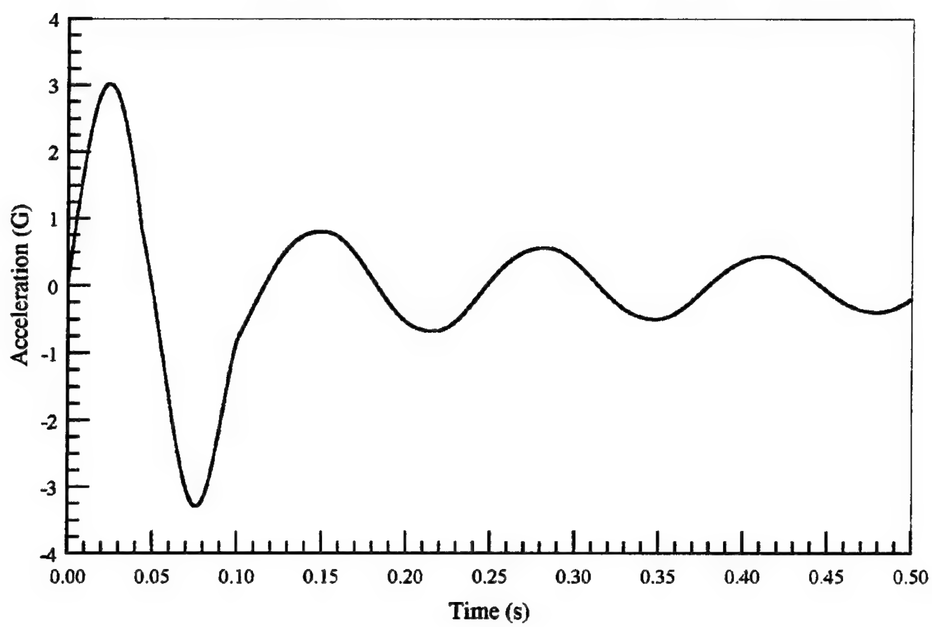


<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	3100.0 psi
Set Chamber Pressure:	14.7 psi
Load Chamber Air Fraction:	25.0% Air
Set Chamber Air Fraction:	40.0% Air

3 G Calibration Pulse (Concept "A")

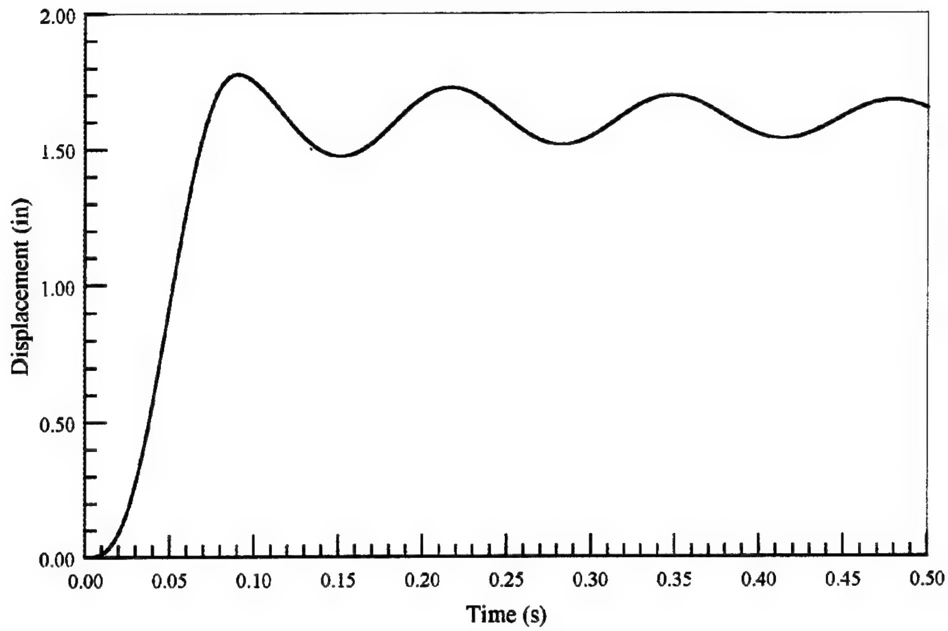


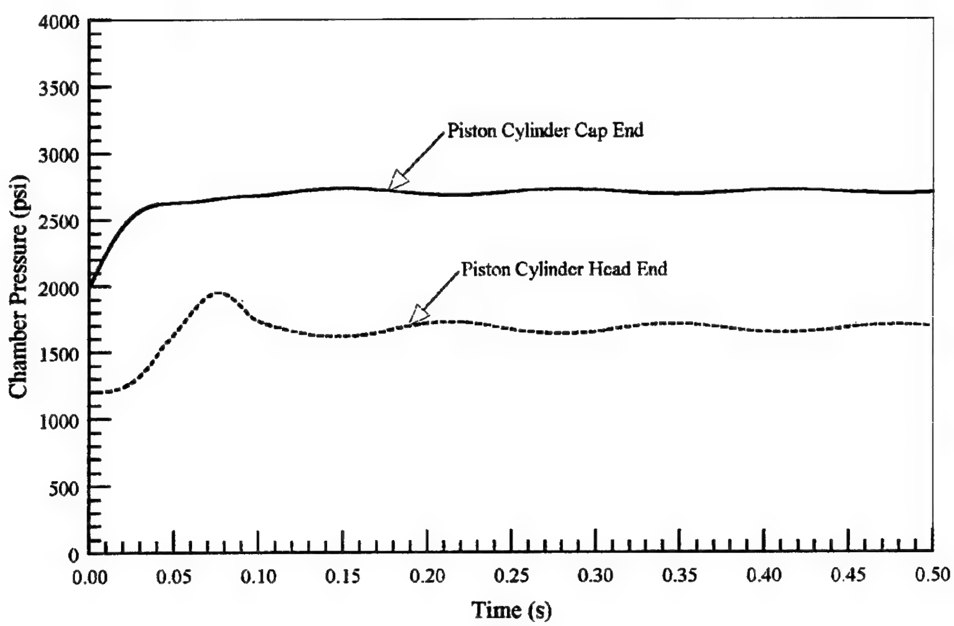


<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type I])

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2700.0 psi
Set Chamber Pressure:	1200.0 psi
Load Chamber Air Fraction:	20.0% Air
Set Chamber Air Fraction:	30.0% Air

3 G Calibration Pulse (Concept "A")

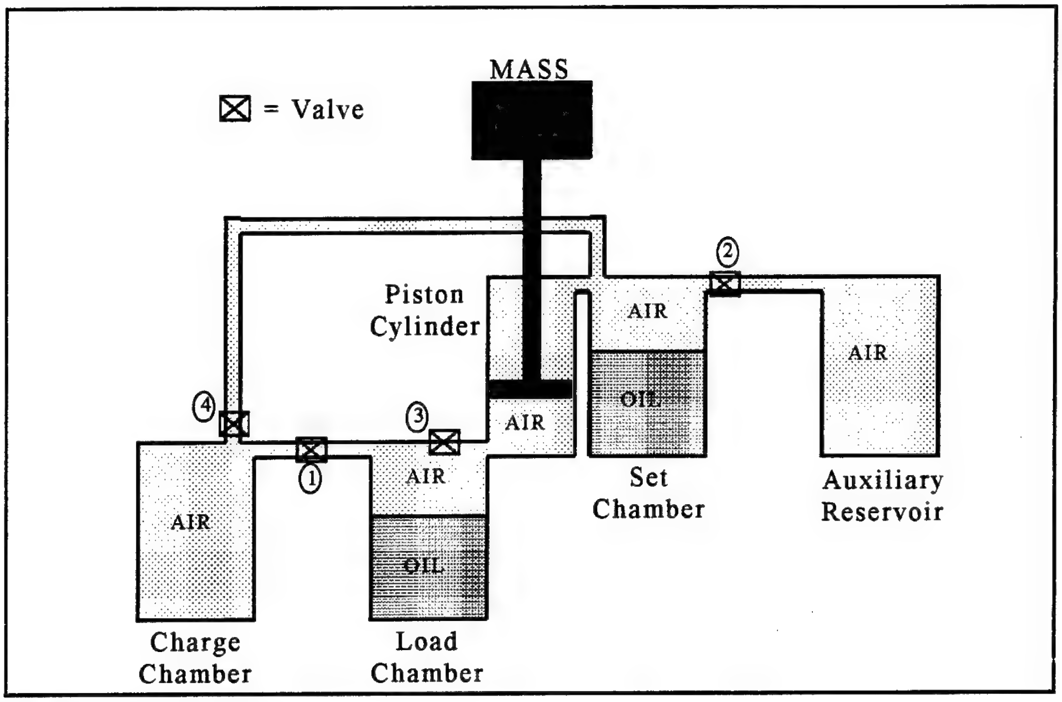




<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type I])

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2700.0 psi
Set Chamber Pressure:	1200.0 psi
Load Chamber Air Fraction:	20.0% Air
Set Chamber Air Fraction:	30.0% Air

All Air Configuration (Concept "B")



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Set Chamber Volume:	325.0 in^3
Auxiliary Reservoir Volume:	20.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Maximum Available Stroke:	14.5 in

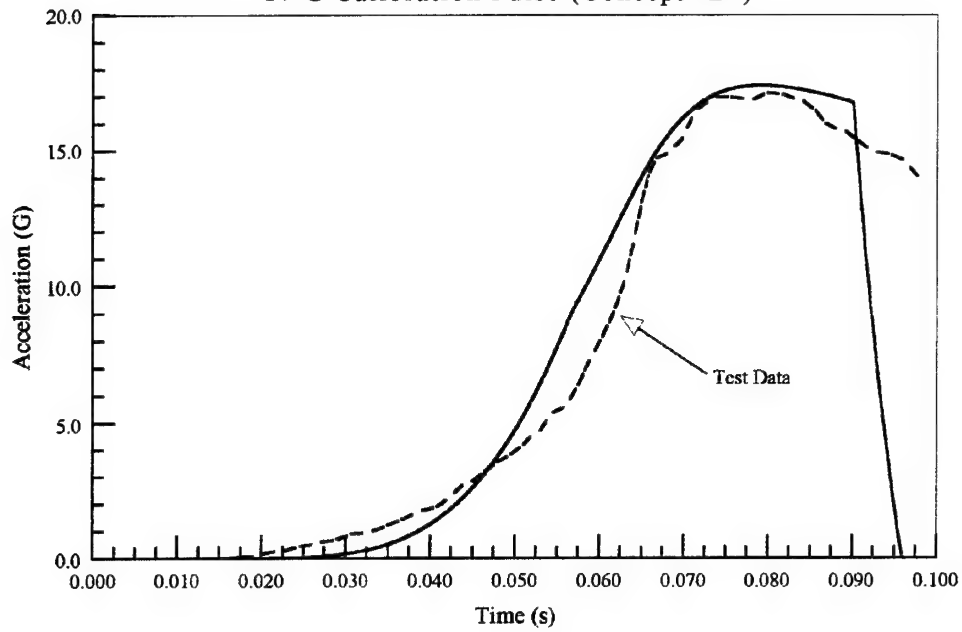
Valve Description

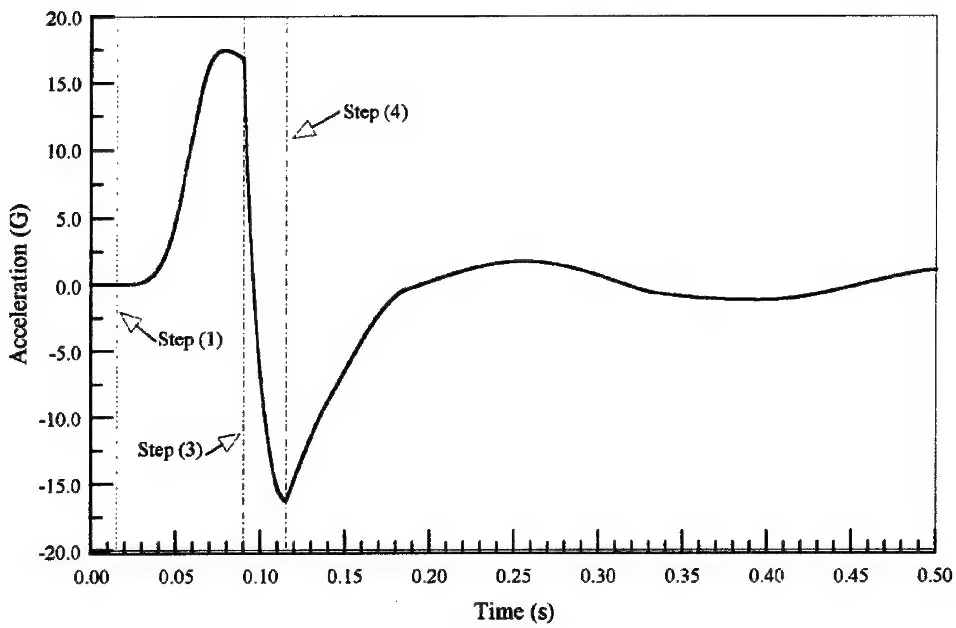
#1: Pneumatic valve used to charge load chamber.
#2: Pressure relief valve. (Only used for calibration pulse.)
#3: Load chamber pressure vent to ambient.
#4: Pneumatic valve used to charge set chamber.

Sequencing Steps

1. Valve #1 is opened; initiating acceleration.
2. Valve #2 provides pressure relief when necessary.
3. Valves #3 & #4 open and valve #1 closes; initiating braking.
4. Valves #3 closes and valve #1 re-opens; bringing system to rest.

17 G Calibration Pulse (Concept "B")

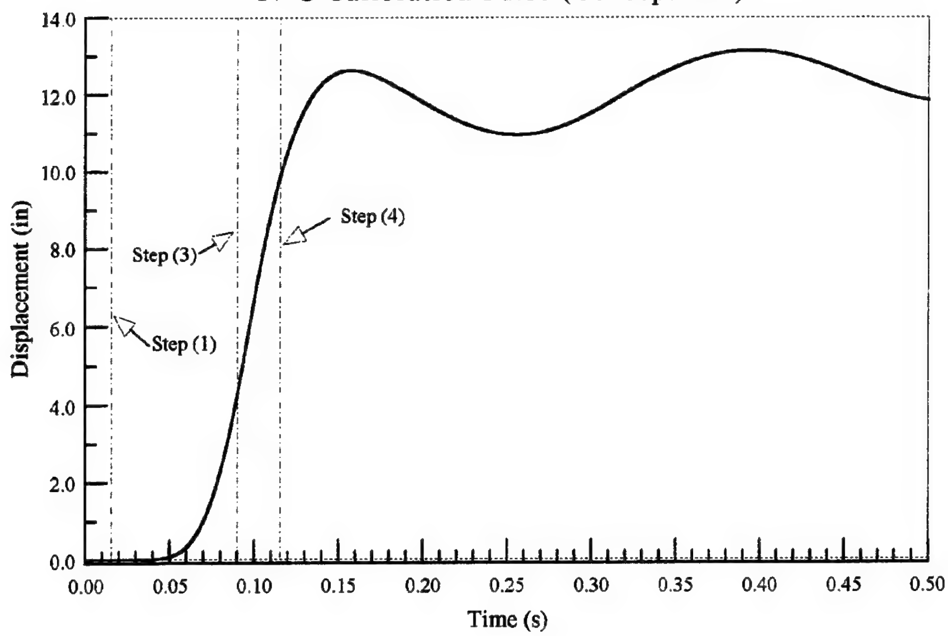


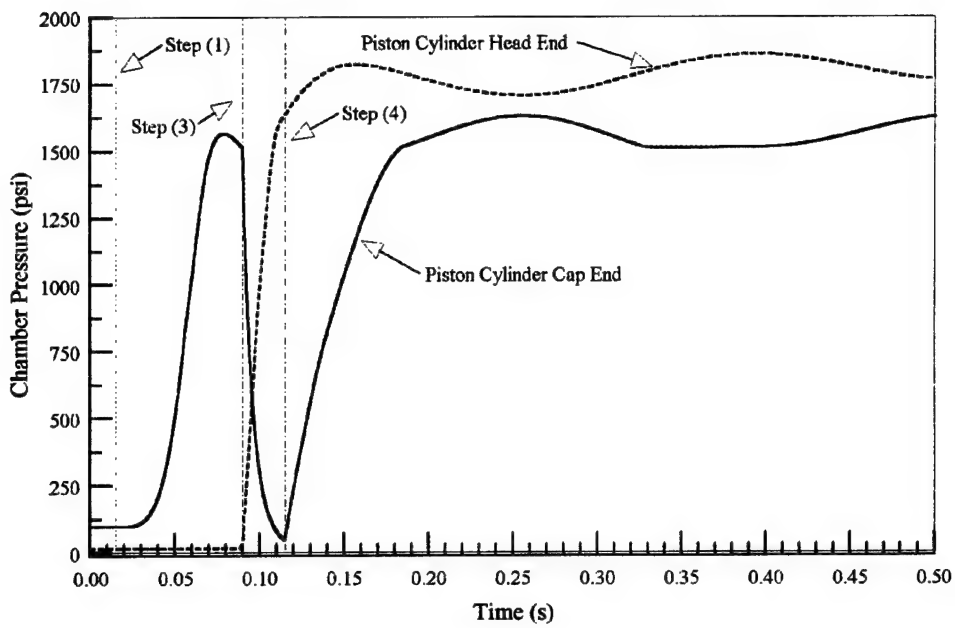


Initial Operating Parameters (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1750.0 psi
Set Chamber Pressure:	14.7 psi
Load Chamber Air Fraction:	15.0% Air
Set Chamber Air Fraction:	50.0% Air

17 G Calibration Pulse (Concept "B")

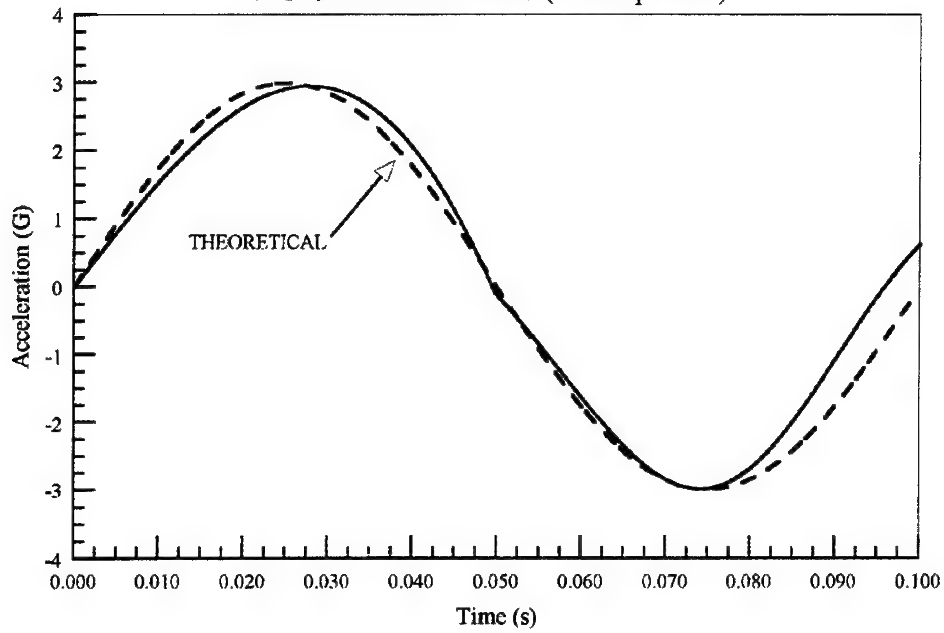


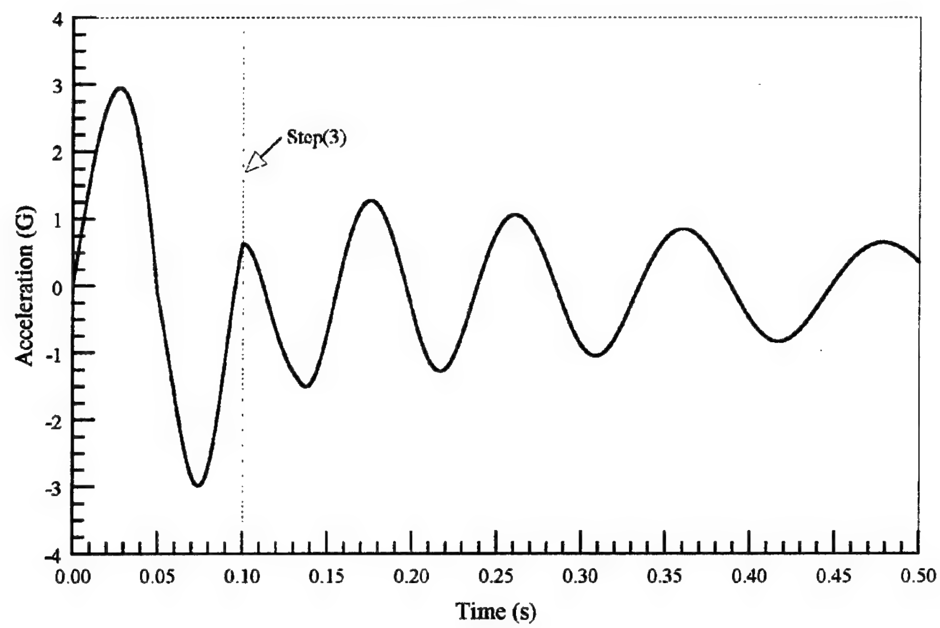


<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1750.0 psi
Set Chamber Pressure:	14.7 psi
Load Chamber Air Fraction:	15.0% Air
Set Chamber Air Fraction:	50.0% Air

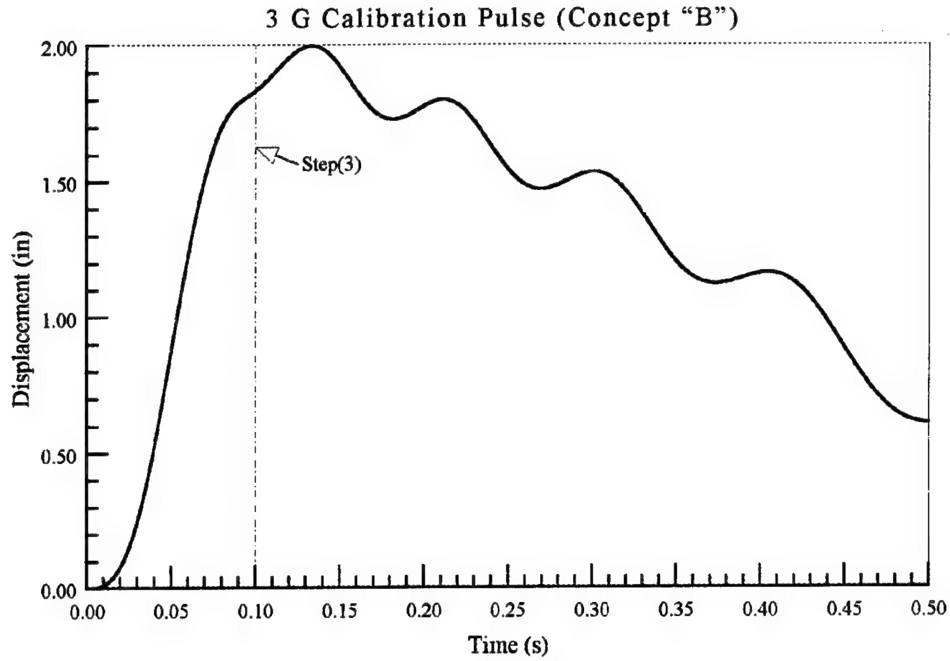
3 G Calibration Pulse (Concept "B")

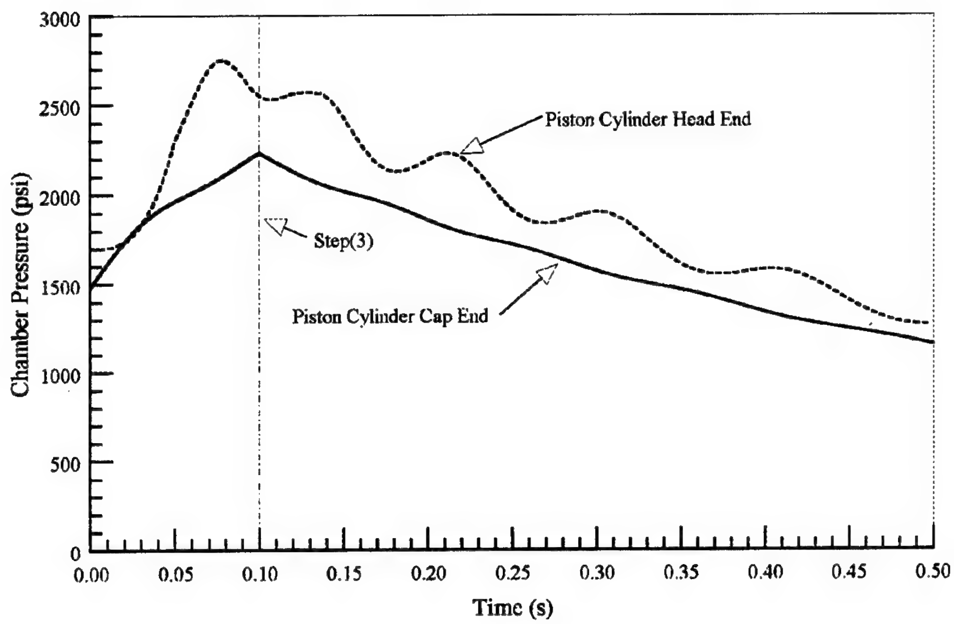




Initial Operating Parameters (3 G -- Calibration Pulse [Type I])

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2400.0 psi
Set Chamber Pressure:	1700.0 psi
Load Chamber Air Fraction:	1.0% Air
Set Chamber Air Fraction:	3.0% Air

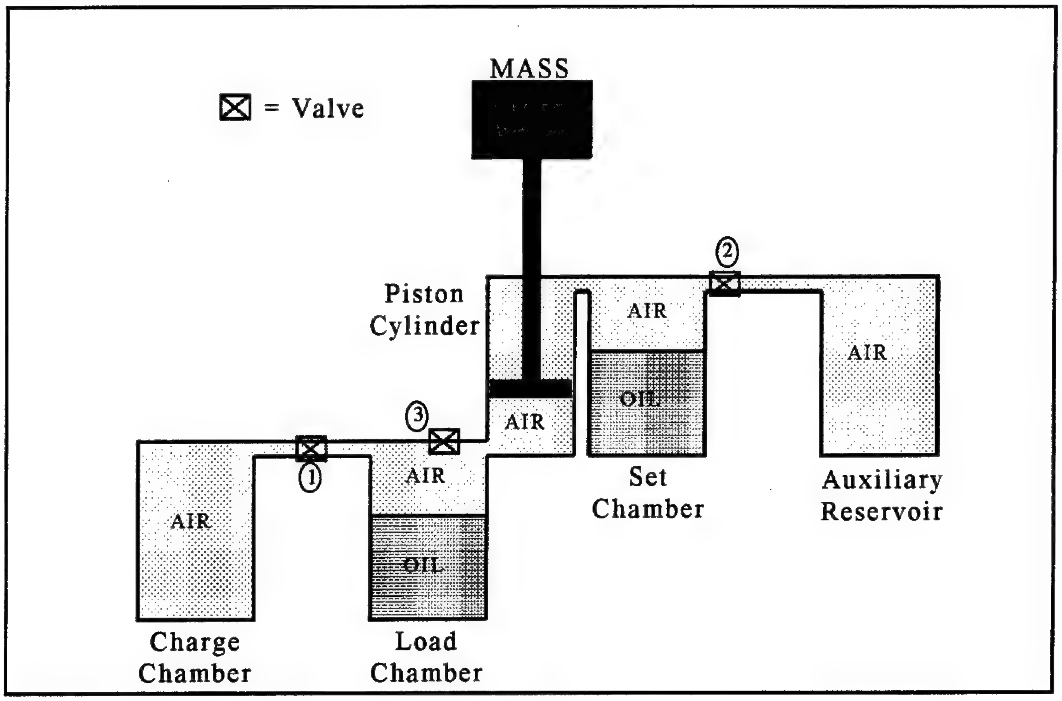




<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type I])

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2400.0 psi
Set Chamber Pressure:	1700.0 psi
Load Chamber Air Fraction:	1.0% Air
Set Chamber Air Fraction:	3.0% Air

All Air Configuration (Concept "C")



Concept Specifications

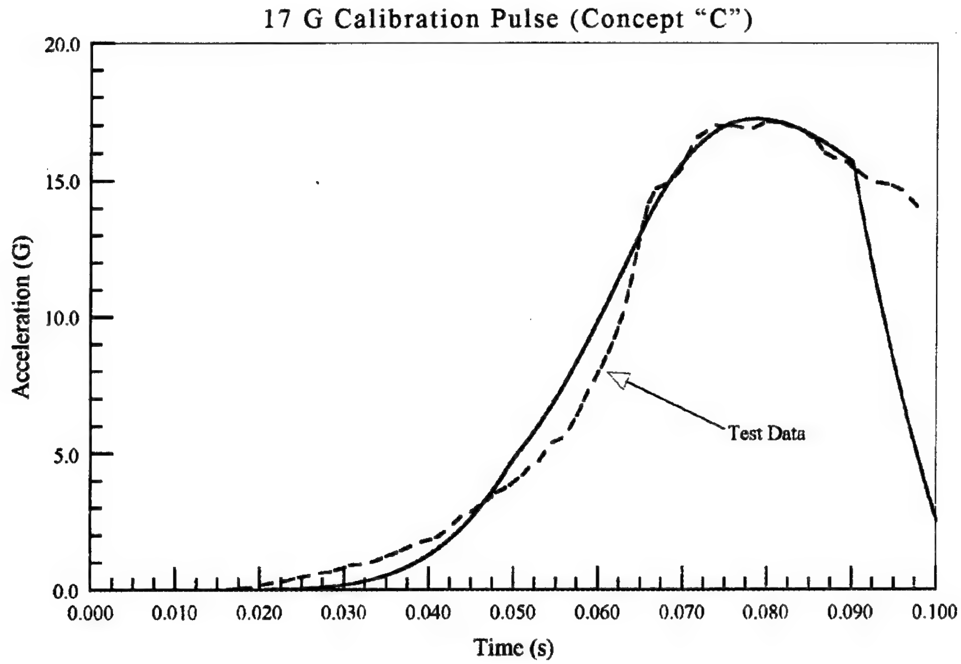
Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Set Chamber Volume:	325.0 in^3
Auxiliary Reservoir Volume:	20.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Maximum Available Stroke:	24.5 in

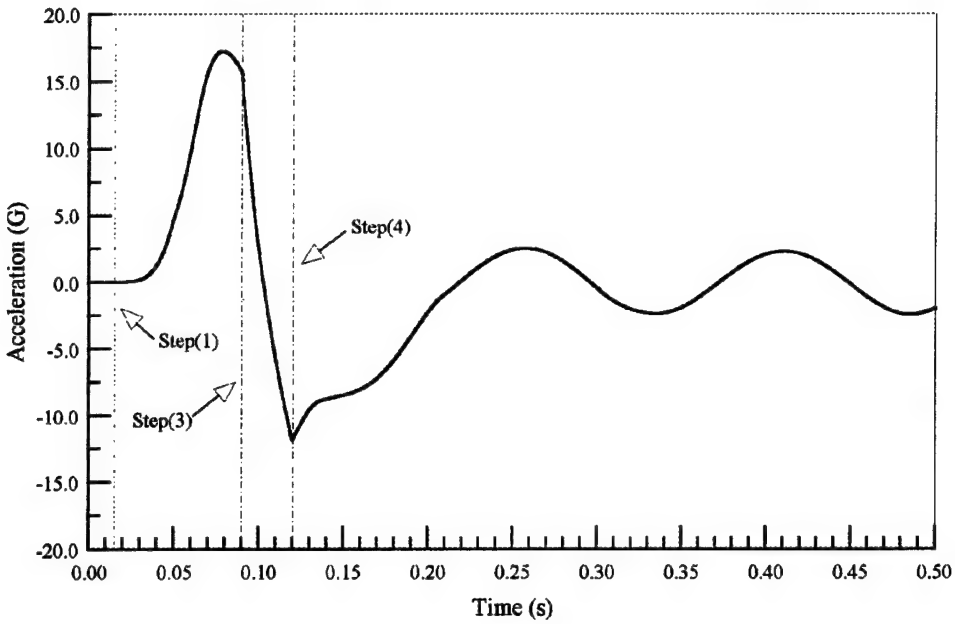
Valve Description

#1: Pneumatic valve used to charge load chamber.
#2: Pressure relief valve. (Only used for calibration pulse.)
#3: Load chamber pressure vent to ambient.

Sequencing Steps

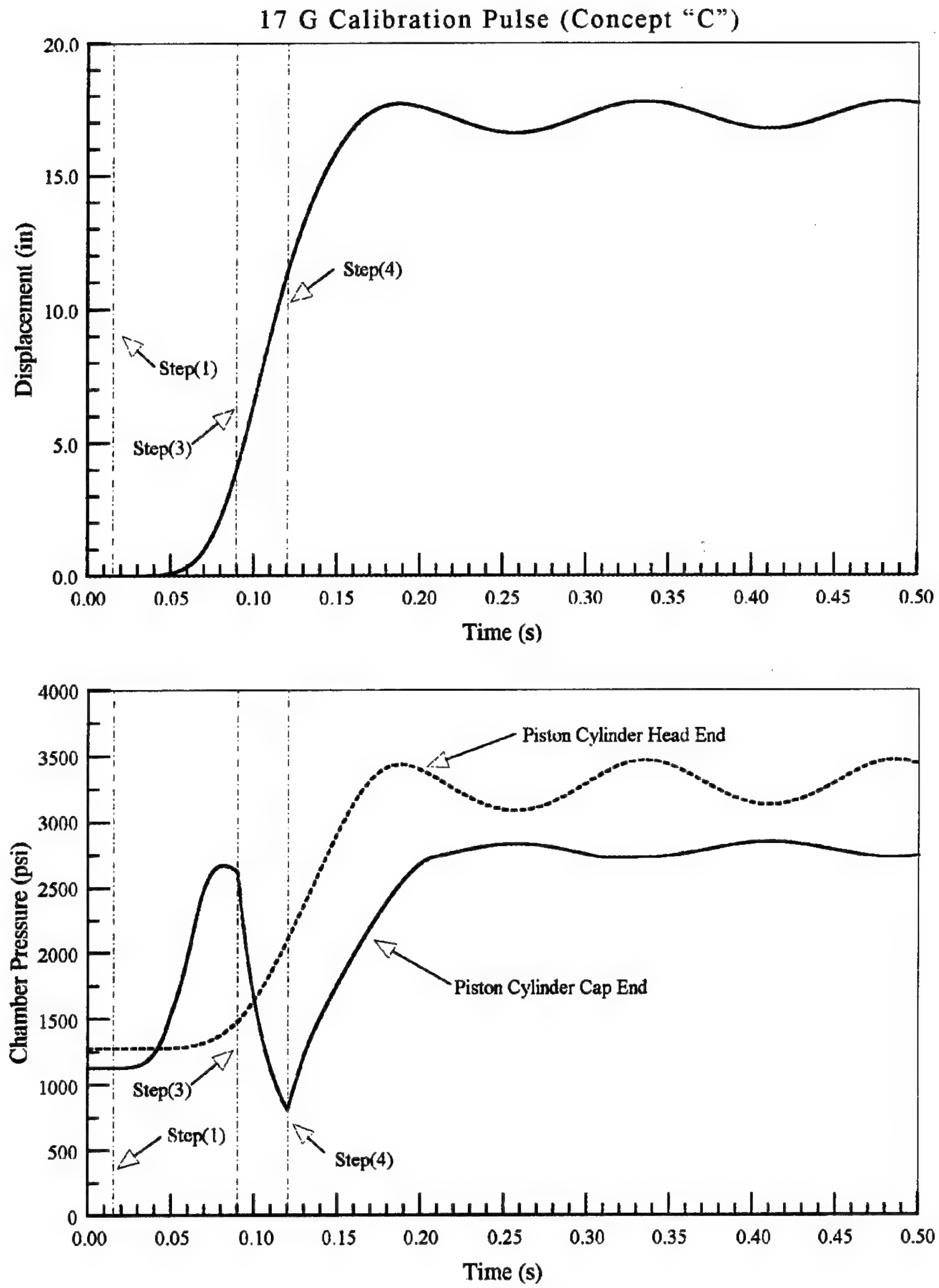
1. Valve #1 is opened; initiating acceleration.
2. Valve #2 provides pressure relief when necessary.
3. Valve #3 opens and valve #1 closes; initiating braking.
4. Valves #3 closes and valve #1 re-opens; bringing system to rest.





<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

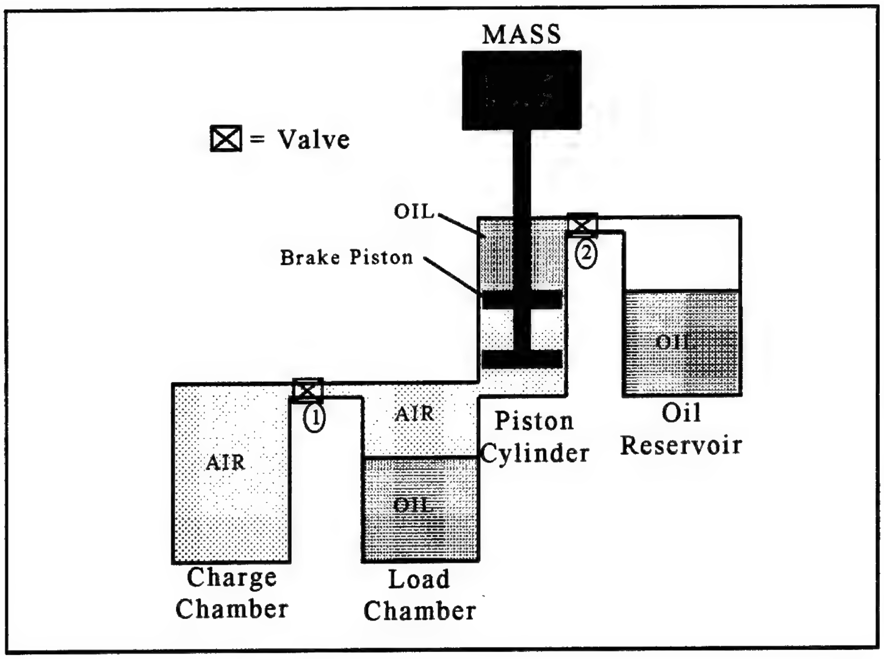
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	3000.0 psi
Set Chamber Pressure:	1275.0 psi
Load Chamber Air Fraction:	25.0% Air
Set Chamber Air Fraction:	10.0% Air



Initial Operating Parameters (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	3000.0 psi
Set Chamber Pressure:	1275.0 psi
Load Chamber Air Fraction:	25.0% Air
Set Chamber Air Fraction:	10.0% Air

All Air Configuration with Brake Piston (Concept "D")



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Load Chamber Volume:	325.0 in^3
Oil Reservoir Volume:	325.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Maximum Available Stroke:	14.0 in

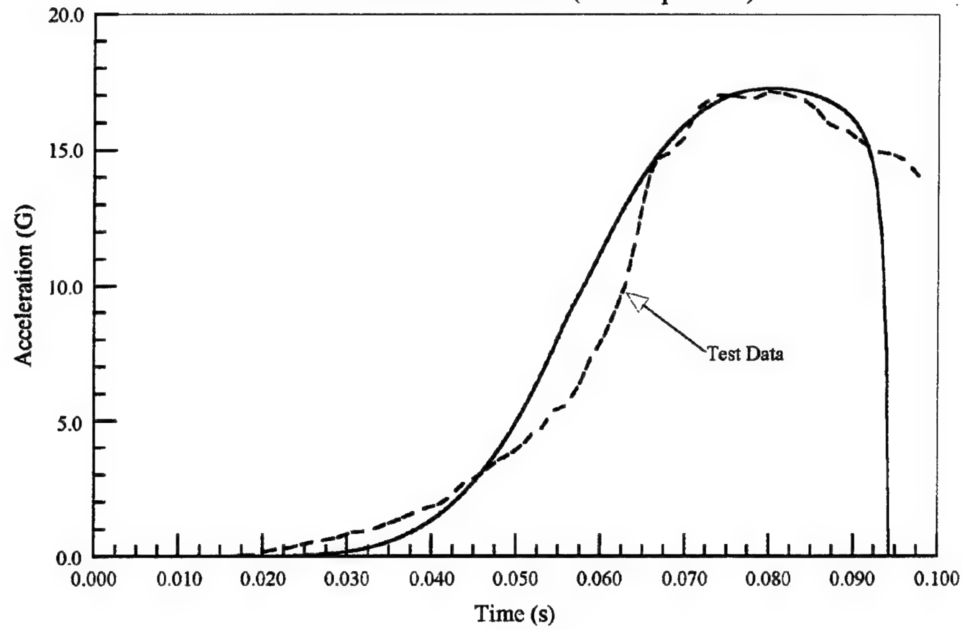
Valve Description

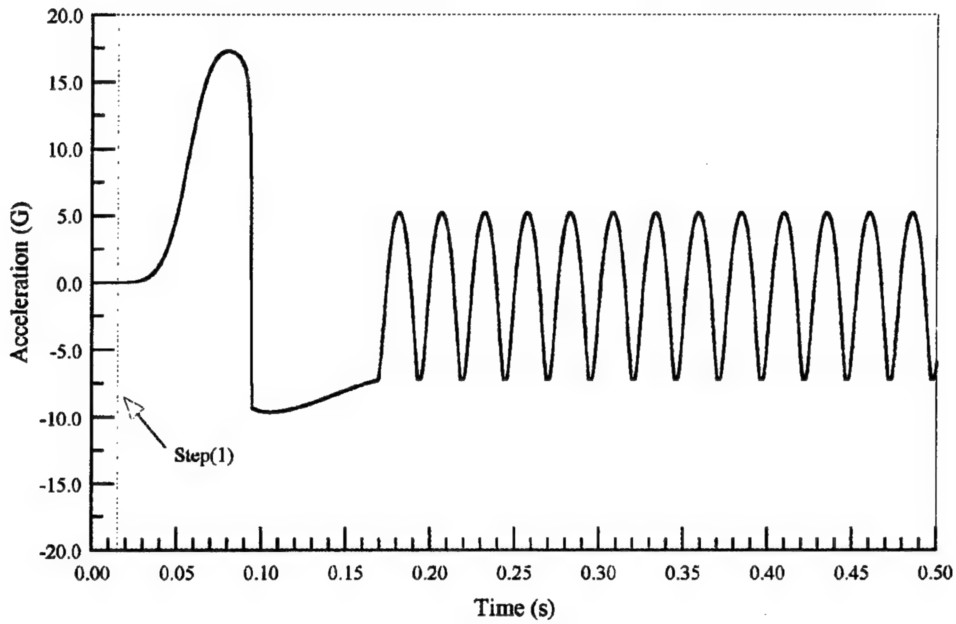
#1: Pneumatic valve used to charge load chamber.
#2: Ideal pressure relief valve.

Sequencing Steps

1. Valve #1 is opened; initiating acceleration.
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

17 G Calibration Pulse (Concept "D")

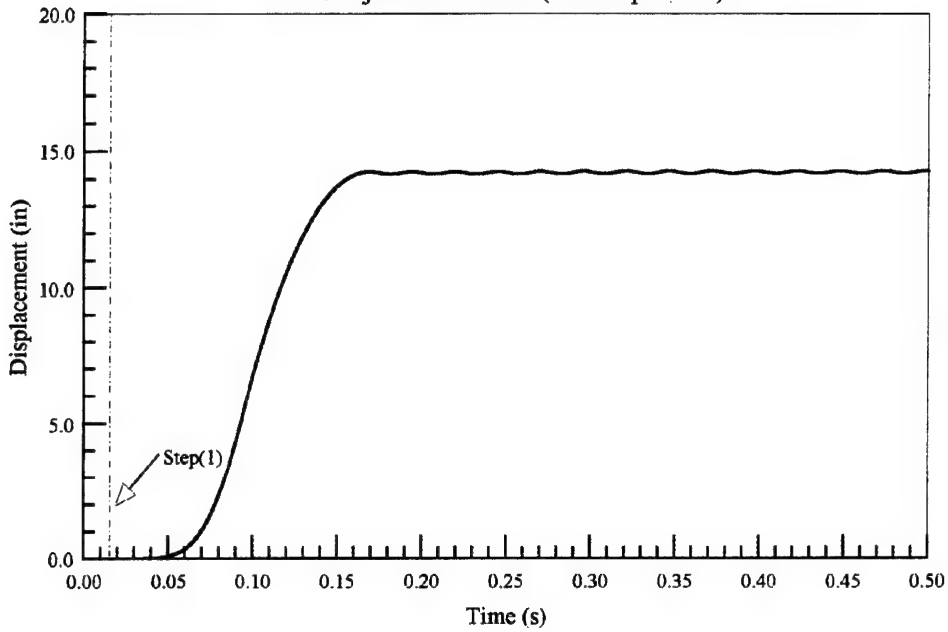


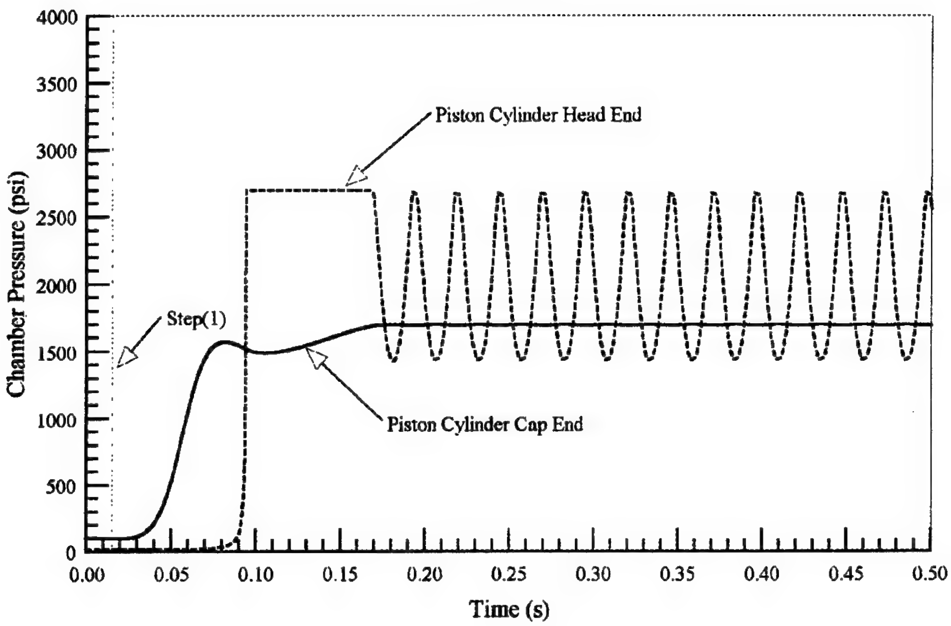


<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1800.0 psi
Load Chamber Air Fraction:	20.0% Air

17 G Ejection Pulse (Concept "D")

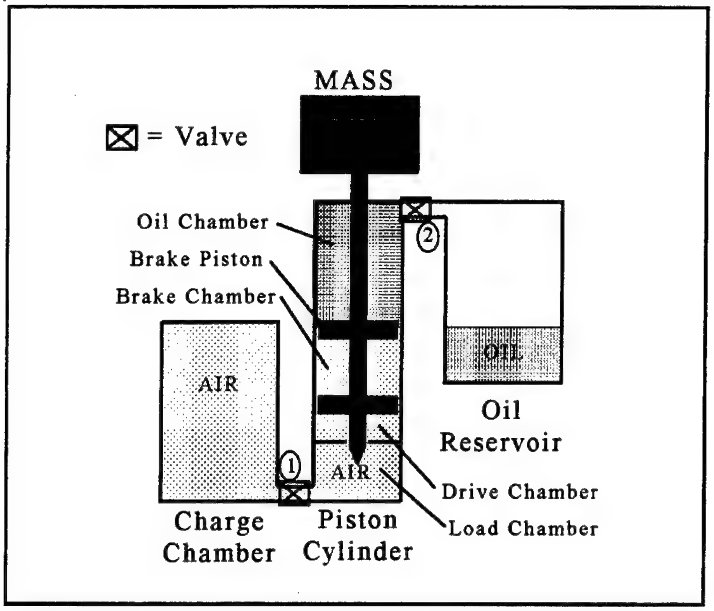




<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1800.0 psi
Load Chamber Air Fraction:	20.0% Air

Metering Pin Configuration (Concept "E")



Concept Specifications

Charge Chamber Volume:	2900.0 in^3
Oil Reservoir Volume:	325.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Total Piston Cylinder Length:	21.0 in
Load Chamber Length:	3.0 in

Metering Pin

Diameter:	1.375 in
Total Length:	3.75 in
Variable Diameter Length:	2.75 in
Orifice Diameter:	1.375 in

Valve Description

#1: Pneumatic valve used to charge load chamber of the Piston Cylinder.
#2: Ideal pressure relief valve.

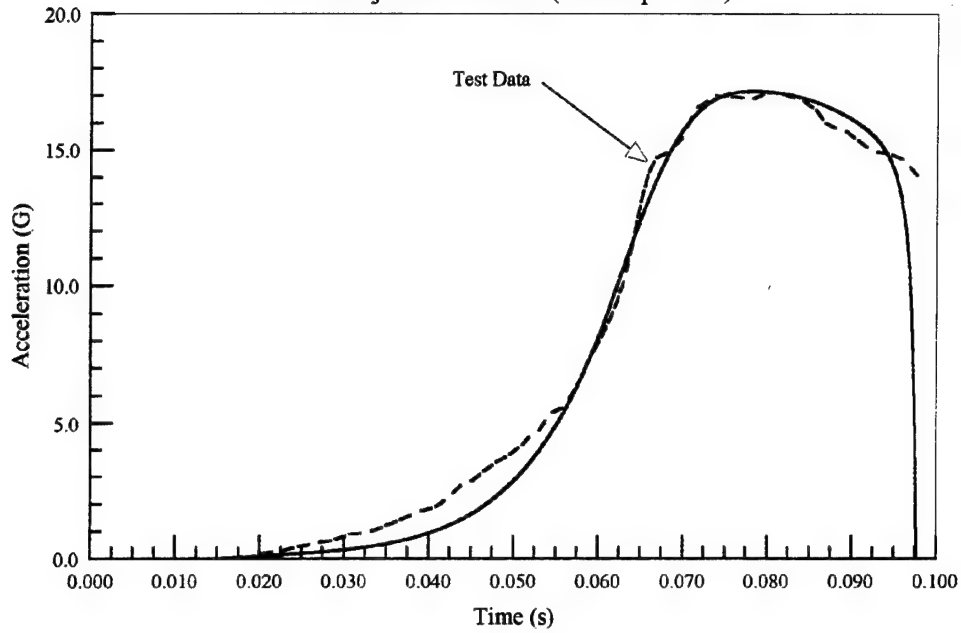
Sequencing Steps when using Valve #1

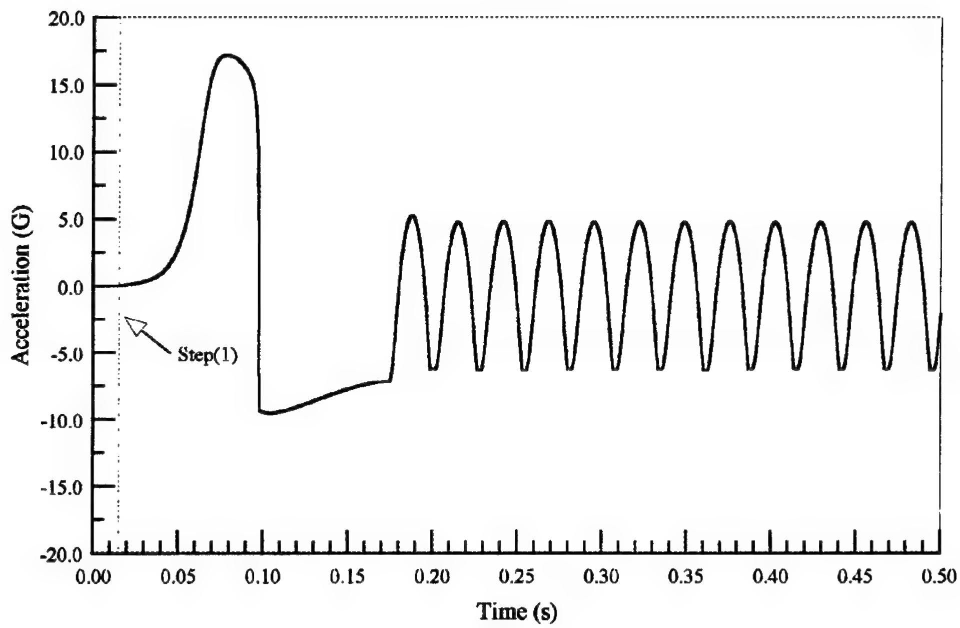
1. Valve #1 is opened; initiating acceleration. (Metering pin starts above orifice.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

Sequencing Steps when not using Valve #1

1. Acceleration is initiated through release of metering pin. (The load chamber of the piston cylinder is in equilibrium with the charge chamber at all times.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

17 G Ejection Pulse (Concept "E")





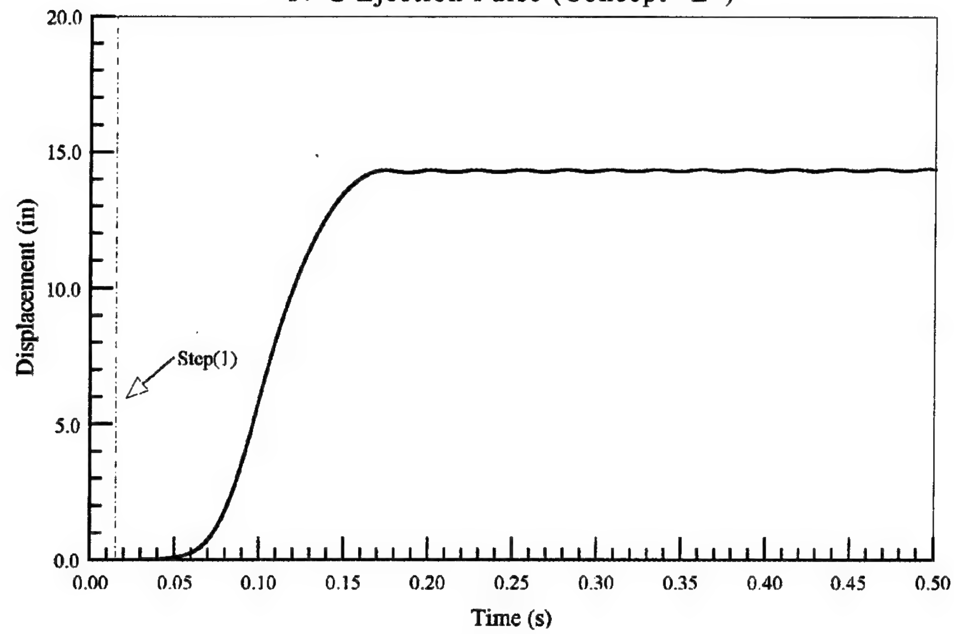
<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

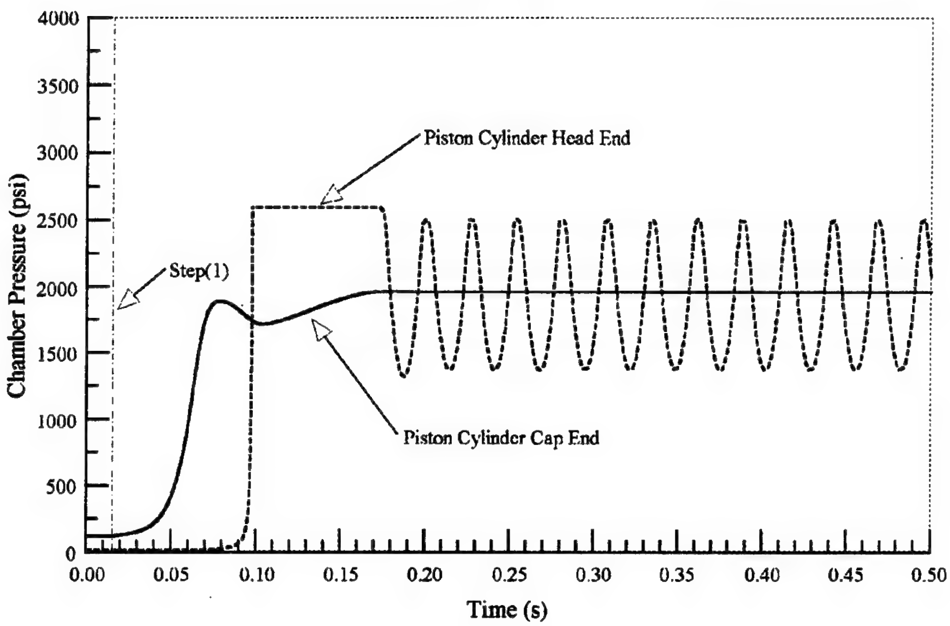
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2050.0 psi
Piston Cylinder Oil Pressure:	14.70 psi
Relief Valve Pressure Setting:	2500.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	1.0 in
Brake Chamber:	5.5 in
Oil Chamber:	13.5 in

17 G Ejection Pulse (Concept "E")





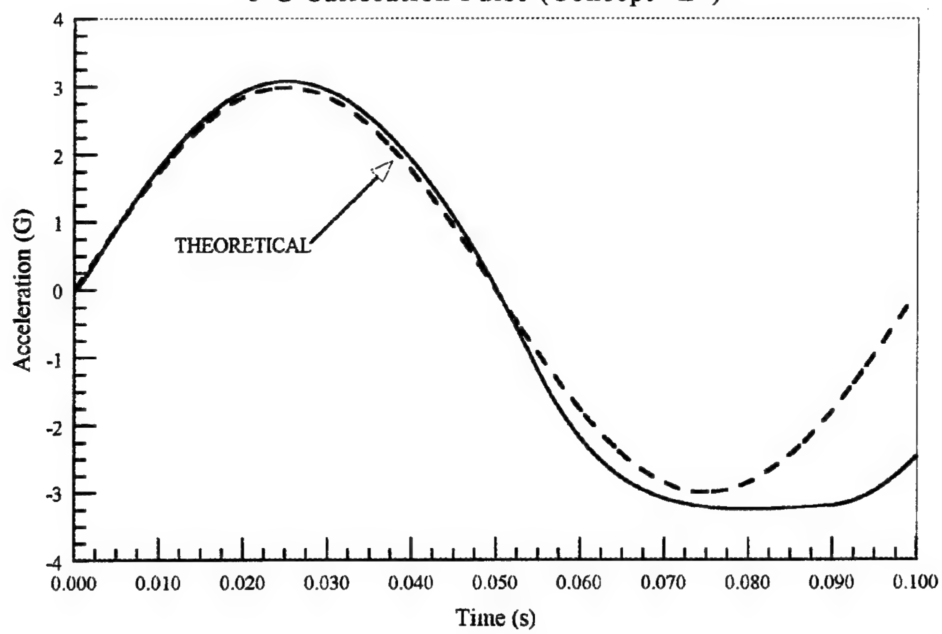
<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

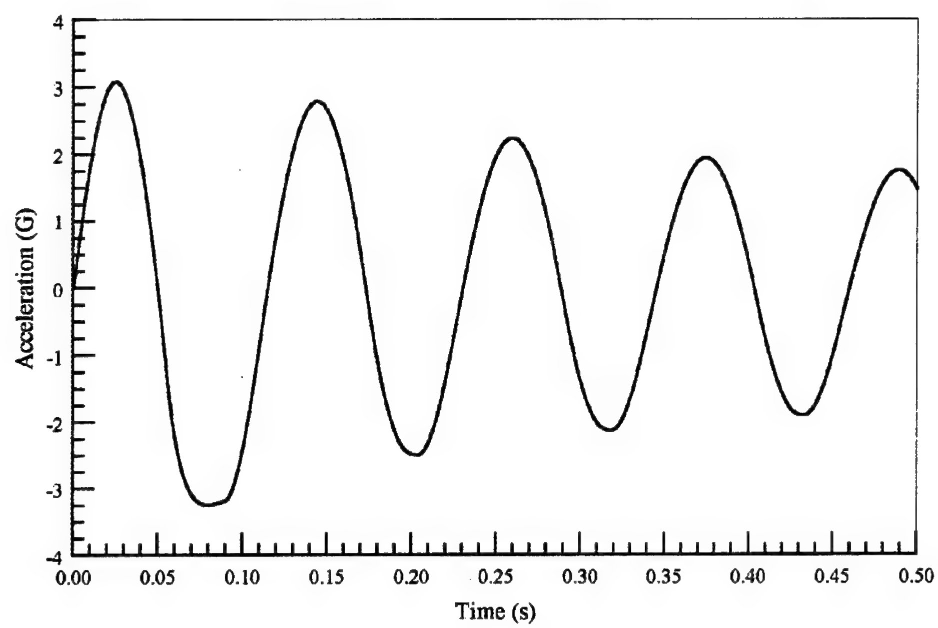
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2050.0 psi
Piston Cylinder Oil Pressure:	14.70 psi
Relief Valve Pressure Setting:	2500.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	1.0 in
Brake Chamber:	5.5 in
Oil Chamber:	13.5 in

3 G Calibration Pulse (Concept "E")

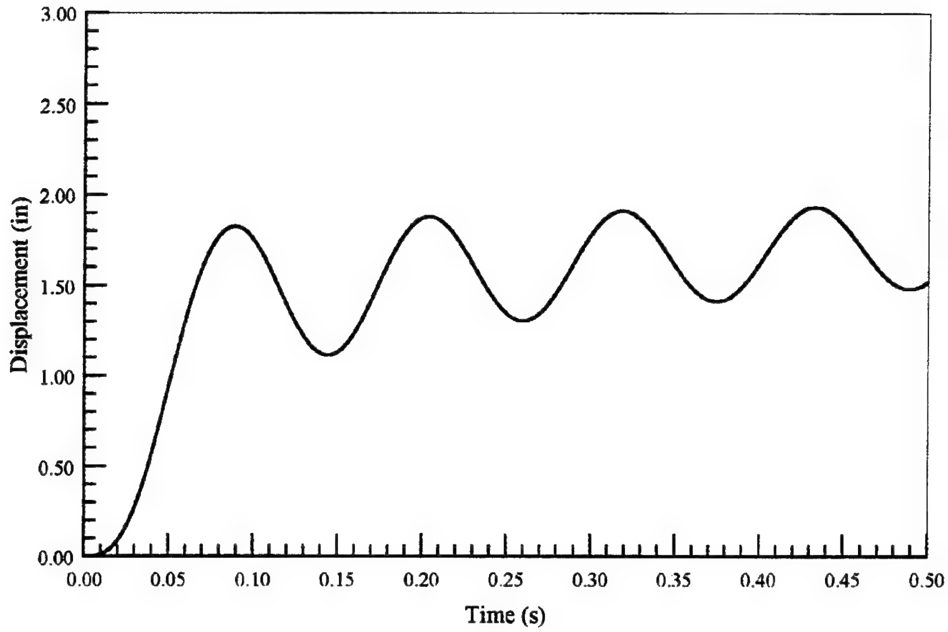


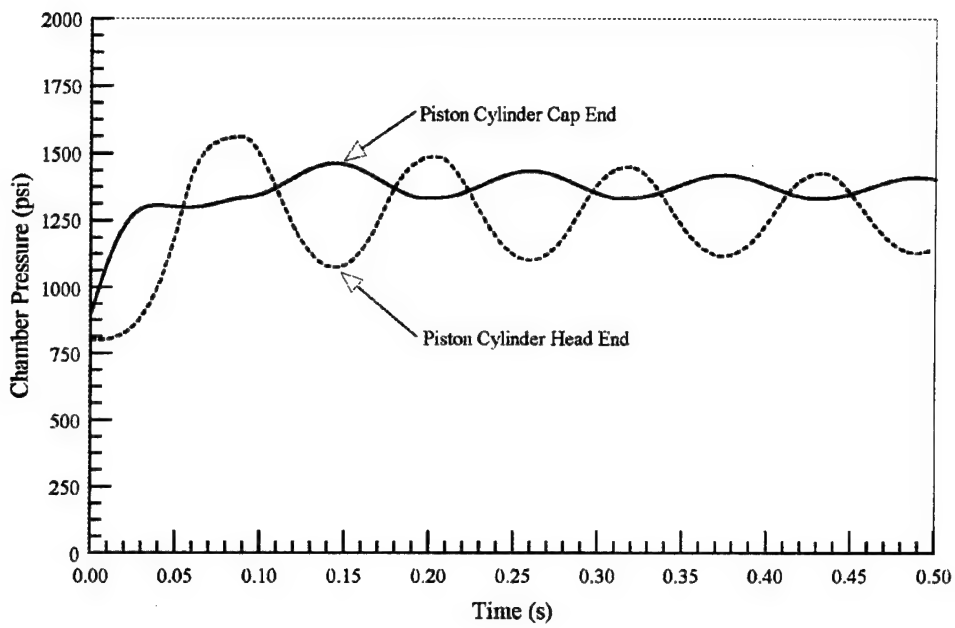


Initial Operating Parameters (3 G -- Calibration Pulse [Type I])

Weight of translating system:	700.0 lb.	Piston Cylinder Chamber Lengths	
Charge Chamber Pressure:	1350.0 psi	Drive Chamber:	3.75 in
Piston Cylinder Oil Pressure:	800.0 psi	Brake Chamber:	3.75 in
Relief Valve Pressure Setting:	1300.0 psi	Oil Chamber:	12.5 in

3 G Calibration Pulse (Concept "E")

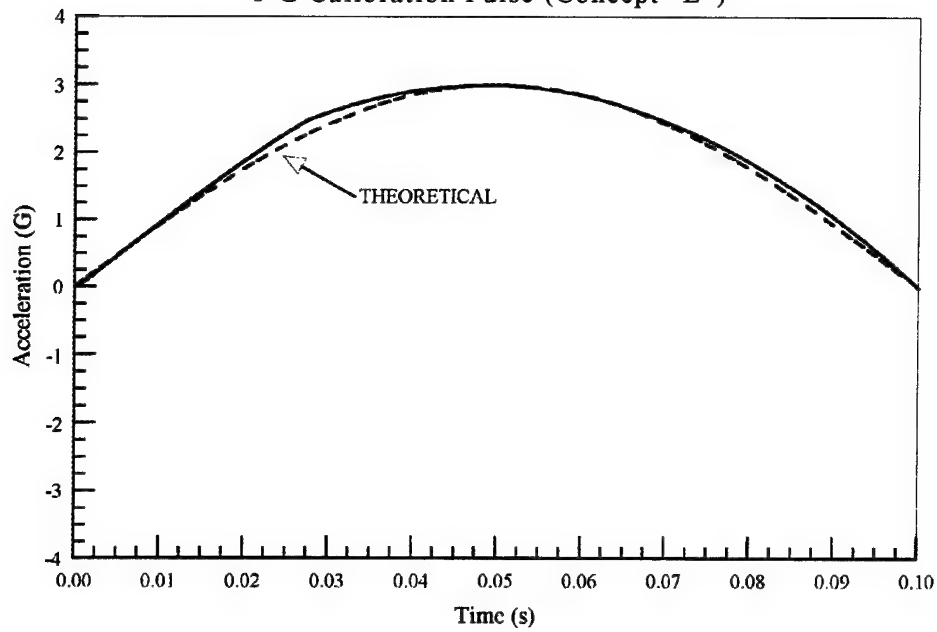


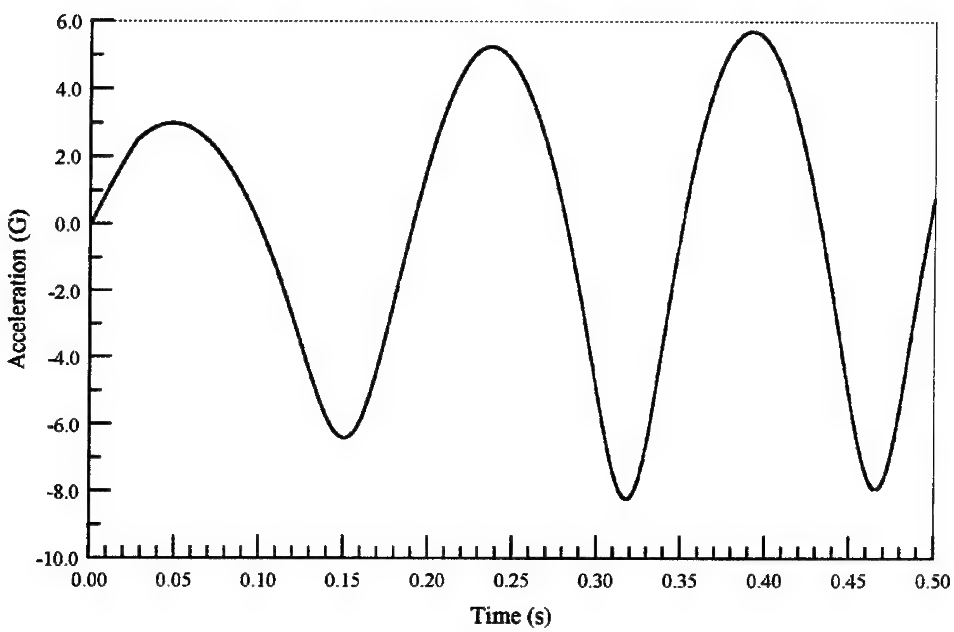


<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type I])

Weight of translating system:	700.0 lb.	<u>Piston Cylinder Chamber Lengths</u>	
Charge Chamber Pressure:	1350.0 psi	Drive Chamber:	3.75 in
Piston Cylinder Oil Pressure:	800.0 psi	Brake Chamber:	3.75 in
Relief Valve Pressure Setting:	1300.0 psi	Oil Chamber:	12.5 in

3 G Calibration Pulse (Concept "E")





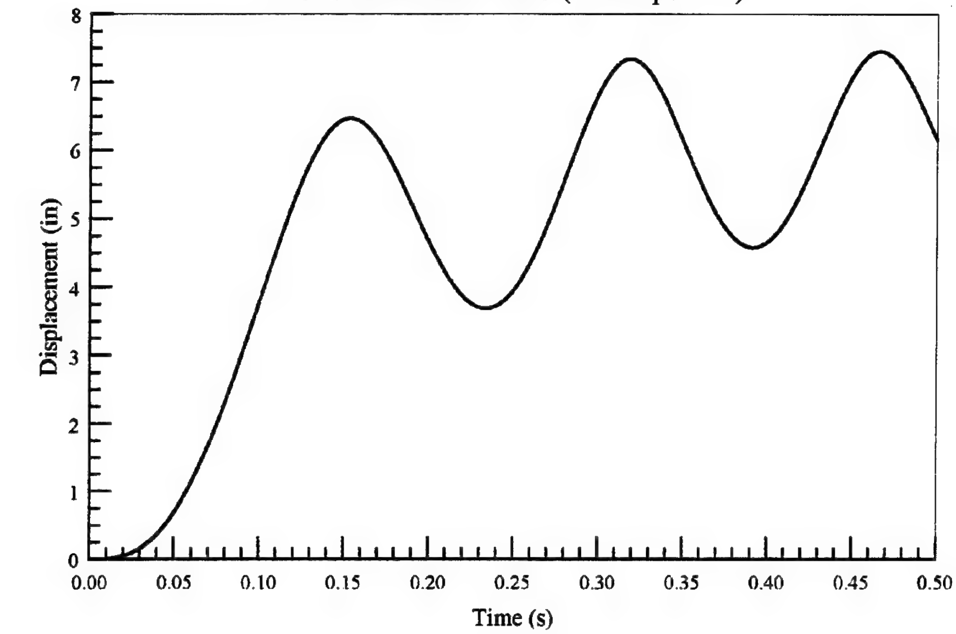
<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type II])

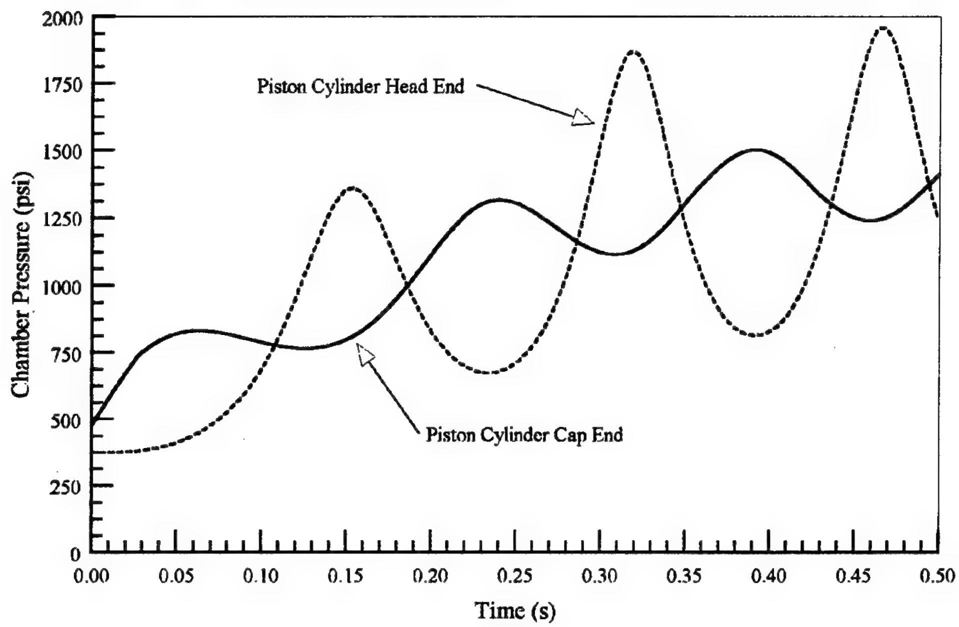
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1400.0 psi
Piston Cylinder Oil Pressure:	375.0 psi
Relief Valve Pressure Setting:	2000.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	3.75 in
Brake Chamber:	10.75 in
Oil Chamber:	5.5 in

3 G Calibration Pulse (Concept "E")

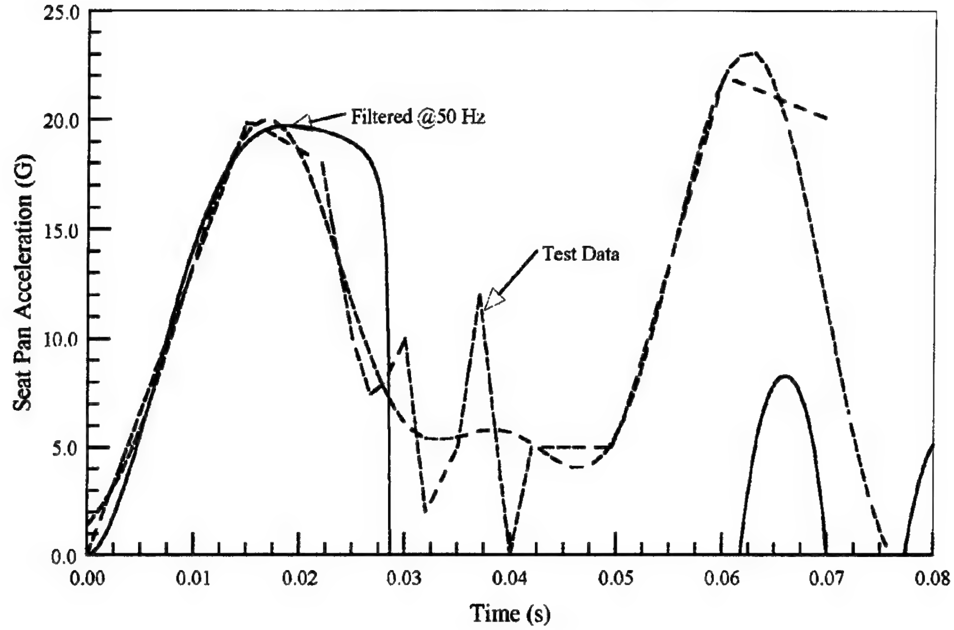


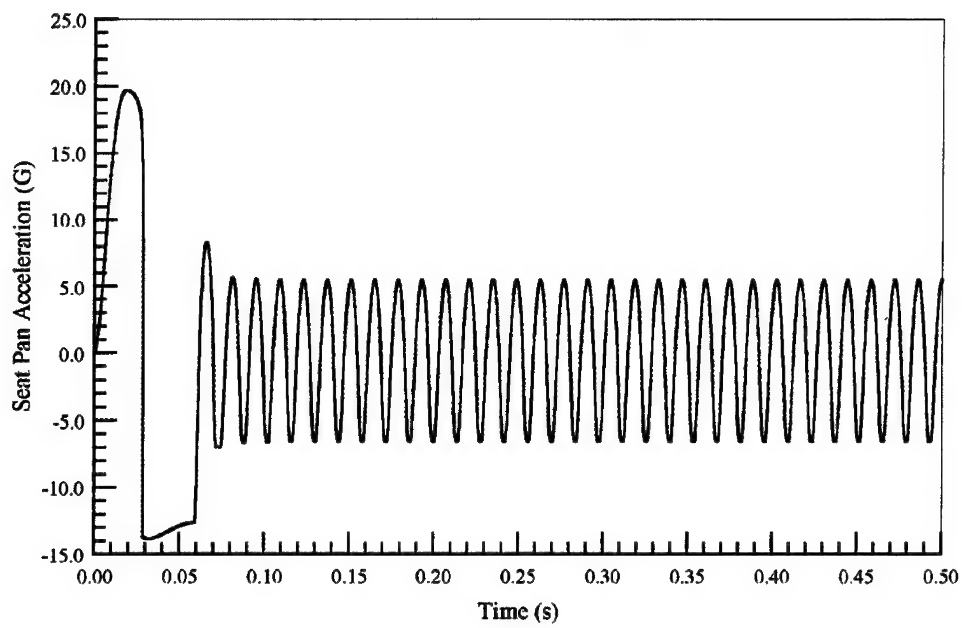


<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type II])

Weight of translating system:	700.0 lb.	<u>Piston Cylinder Chamber Lengths</u>	
Charge Chamber Pressure:	1400.0 psi	Drive Chamber:	3.75 in
Piston Cylinder Oil Pressure:	375.0 psi	Brake Chamber:	10.75 in
Relief Valve Pressure Setting:	2000.0 psi	Oil Chamber:	5.5 in

V-22 Crashworthy Seat (Concept "E")

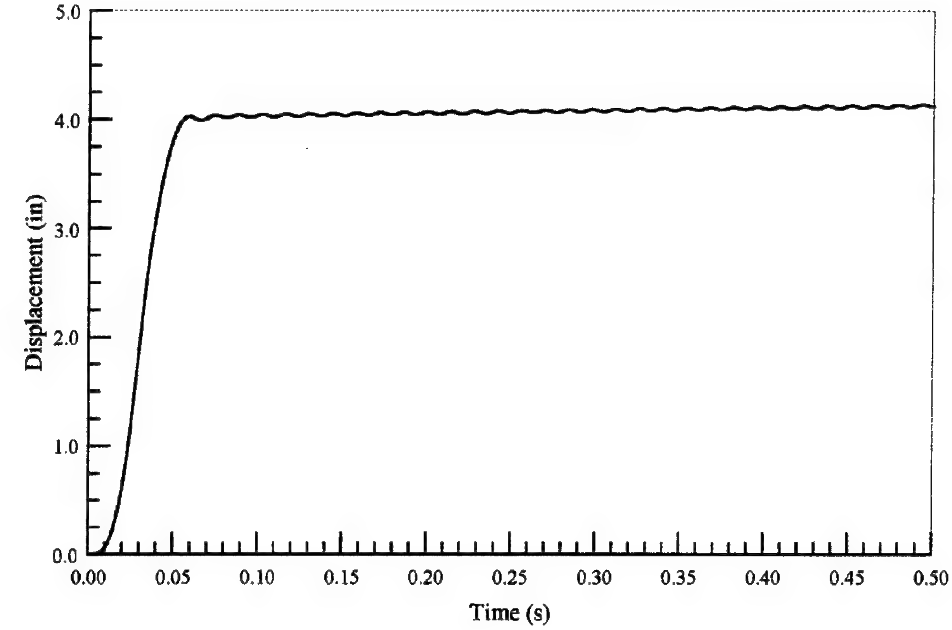


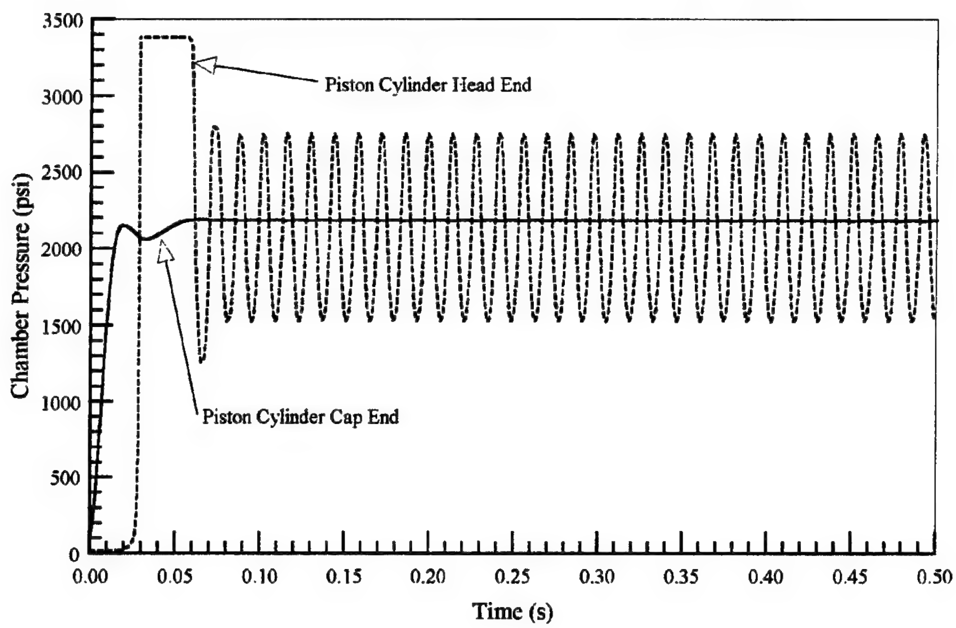


<u>Initial Operating Parameters</u> (20 G – Crashworthy Seating Pulse)

Weight of translating system:	700.0 lb.	<u>Piston Cylinder Chamber Lengths</u>	
Charge Chamber Pressure:	2250.0 psi	Drive Chamber:	3.75 in
Piston Cylinder Oil Pressure:	14.70 psi	Brake Chamber:	1.75 in
Relief Valve Pressure Setting:	2500.0 psi	Oil Chamber:	14.5 in

V-22 Crashworthy Seat (Concept "E")





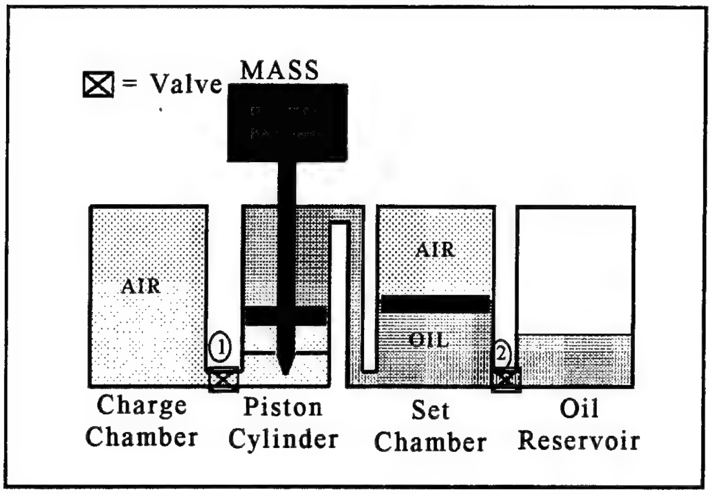
<u>Initial Operating Parameters</u> (20 G – Crashworthy Seating Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2250.0 psi
Piston Cylinder Oil Pressure:	14.70 psi
Relief Valve Pressure Setting:	2500.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	3.75 in
Brake Chamber:	1.75 in
Oil Chamber:	14.5 in

Metering Pin Configuration (Concept "F")



Concept Specifications

Charge Chamber Volume:	2310.0 in^3
Oil Reservoir Volume:	325.0 in^3
Piston Diameter:	3.25 in
Rod Diameter:	1.375 in
Total Piston Cylinder Length:	21.0 in
Load Chamber Length:	3.0 in

Metering Pin

Diameter:	1.375 in
Total Length:	3.75 in
Variable Diameter Length:	2.75 in
Orifice Diameter:	1.375 in

Valve Description

#1: Pneumatic valve used to charge load chamber of the Piston Cylinder.
#2: Ideal pressure relief valve.

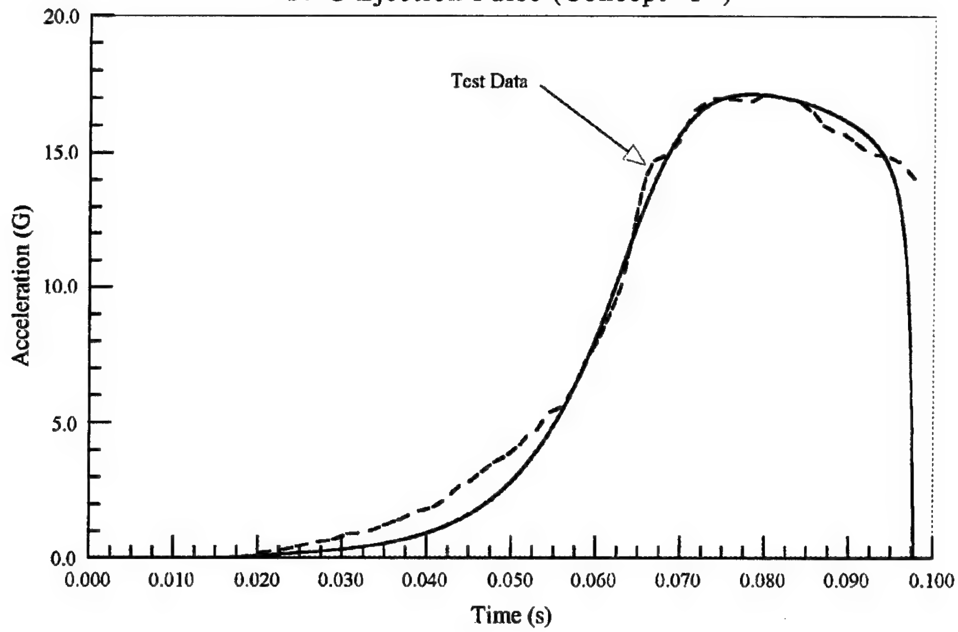
Sequencing Steps when using Valve #1

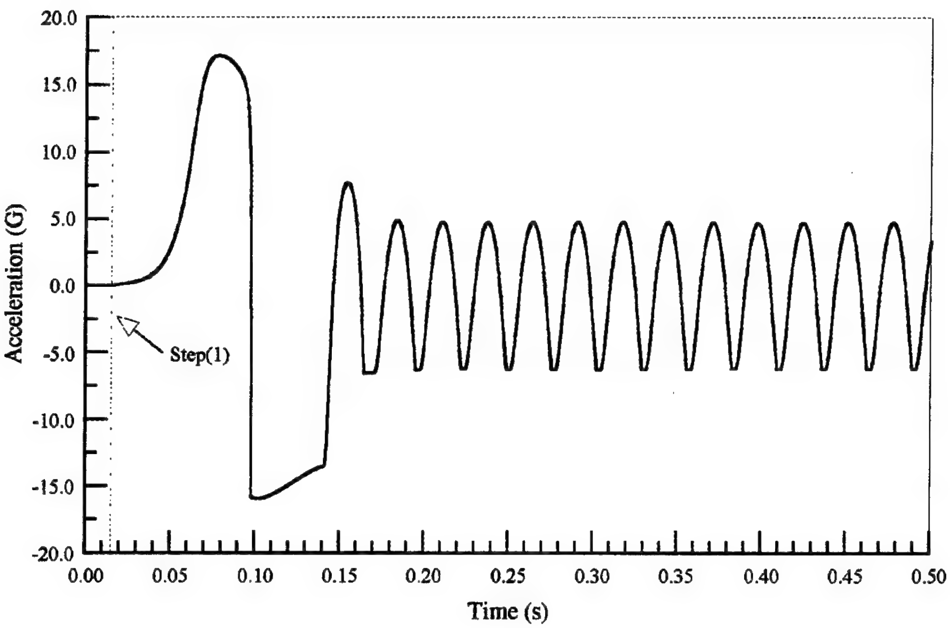
1. Valve #1 is opened; initiating acceleration. (Metering pin starts above orifice.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

Sequencing Steps when not using Valve #1

1. Acceleration is initiated through release of metering pin. (The load chamber of the piston cylinder is in equilibrium with the charge chamber at all times.)
2. Valve #2 actuates only while chamber pressure exceeds threshold pressure.
3. System returns to rest without further intervention.

17 G Ejection Pulse (Concept "F")





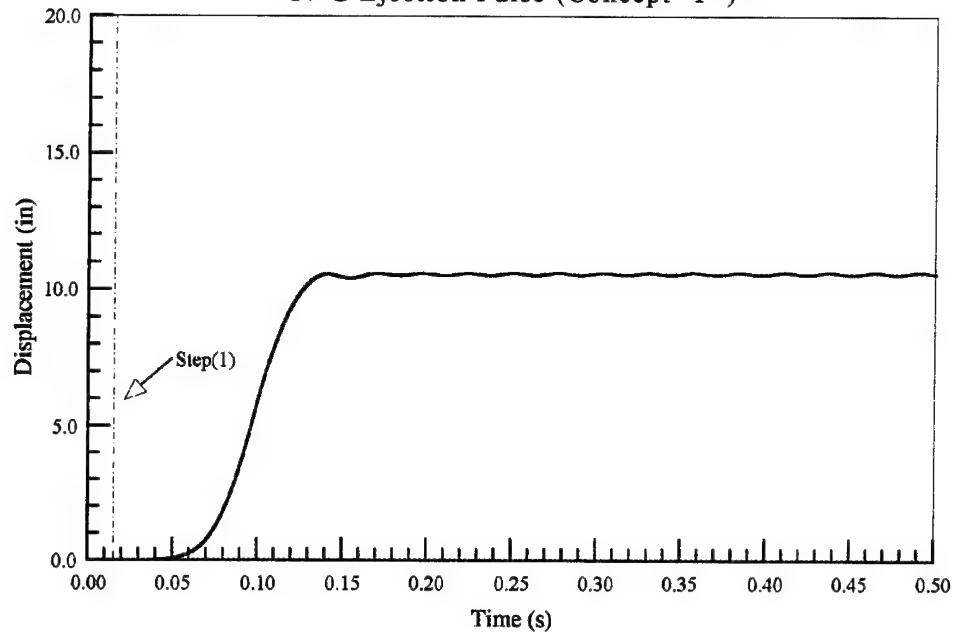
<u>Initial Operating Parameters</u> (17 G -- Ejection Pulse)

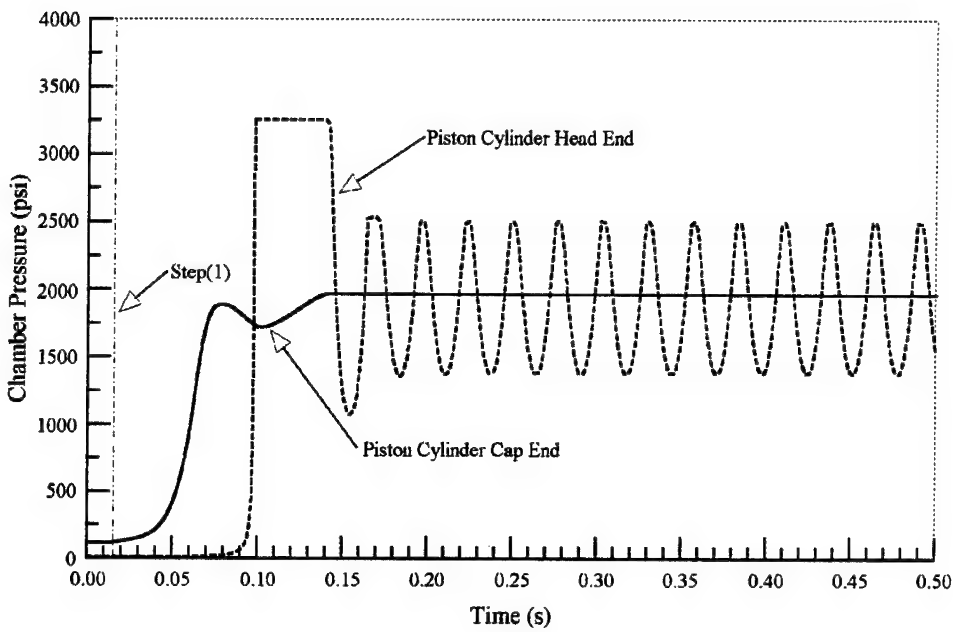
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2050.0 psi
Piston Cylinder Oil Pressure:	14.70 psi
Relief Valve Pressure Setting:	2500.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	1.0 in
Brake Chamber:	5.5 in
Oil Chamber:	13.5 in

17 G Ejection Pulse (Concept “F”)



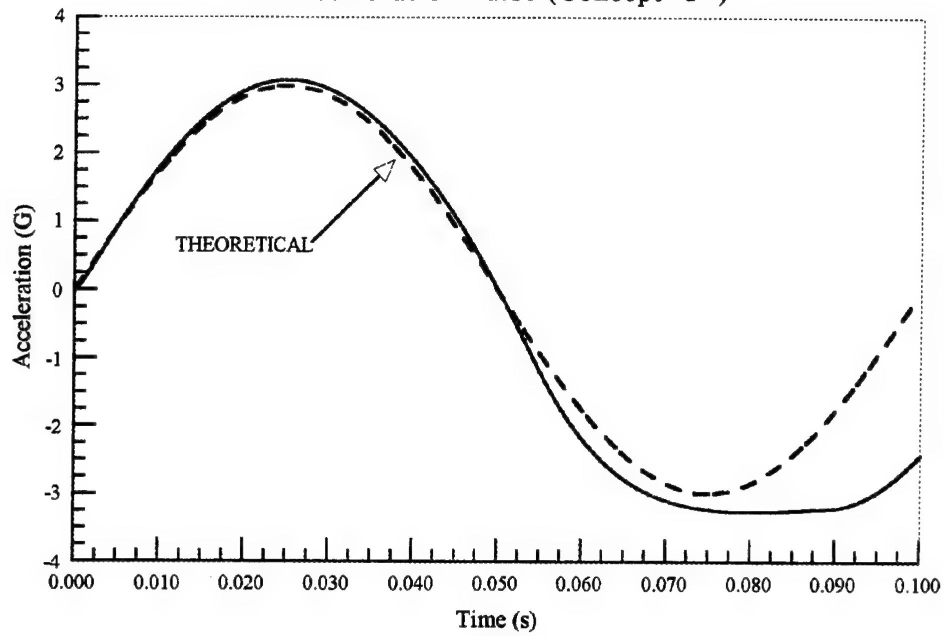


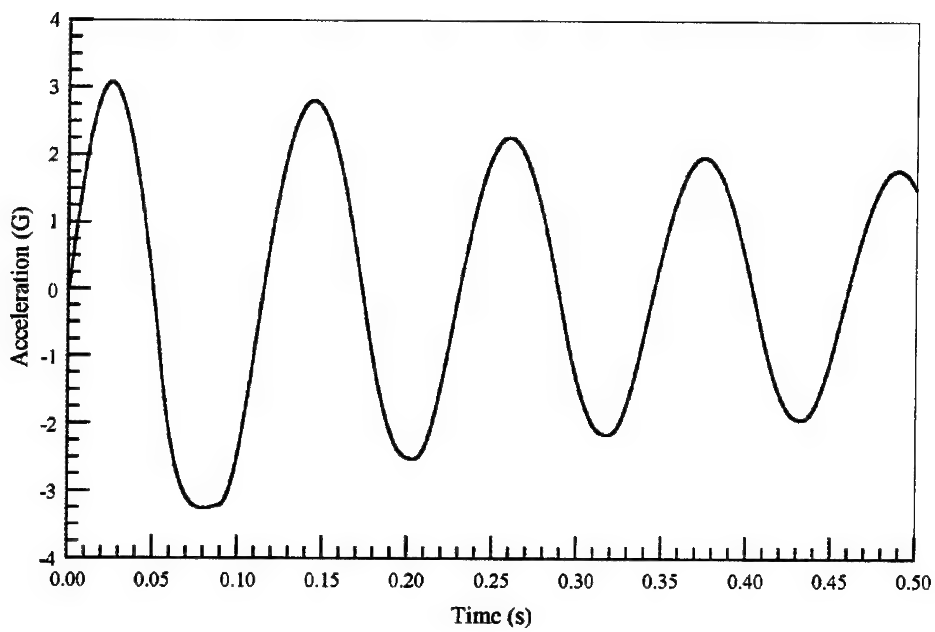
Initial Operating Parameters (17 G -- Ejection Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2050.0 psi
Piston Cylinder Oil Pressure:	14.70 psi
Relief Valve Pressure Setting:	2500.0 psi

Piston Cylinder Chamber Lengths	
Drive Chamber:	1.0 in
Brake Chamber:	5.5 in
Oil Chamber:	13.5 in

3 G Calibration Pulse (Concept "F")

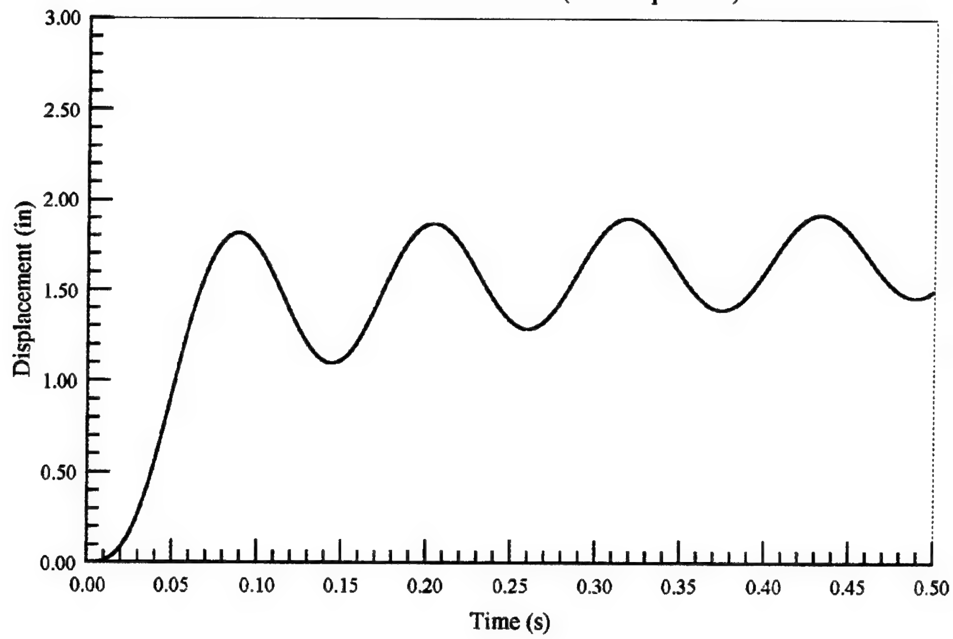


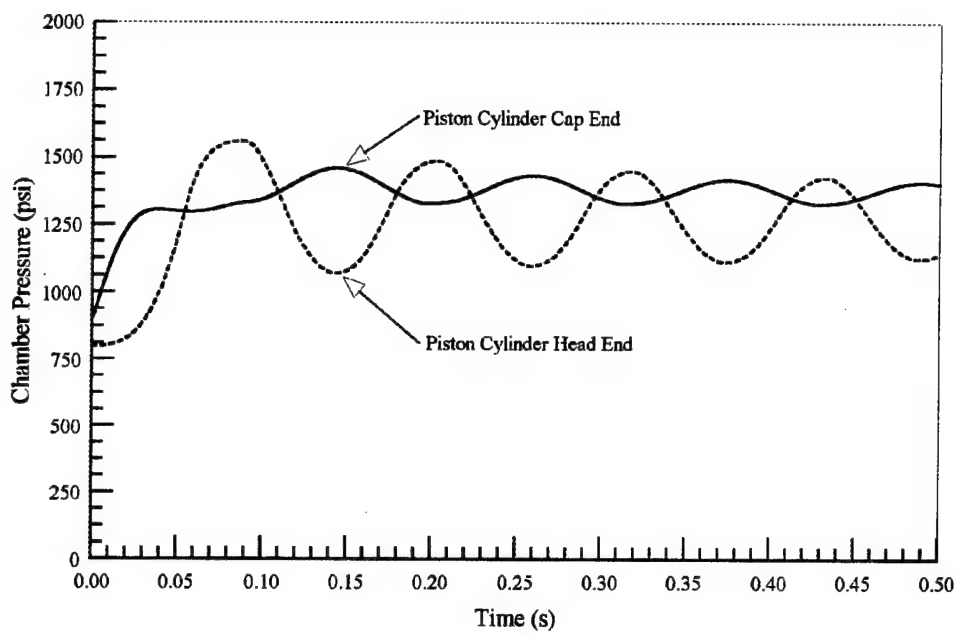


<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type I])

Weight of translating system:	700.0 lb.	<u>Piston Cylinder Chamber Lengths</u>	
Charge Chamber Pressure:	1350.0 psi	Drive Chamber:	3.75 in
Piston Cylinder Oil Pressure:	800.0 psi	Brake Chamber:	3.75 in
Relief Valve Pressure Setting:	1300.0 psi	Oil Chamber:	12.5 in

3 G Calibration Pulse (Concept "F")





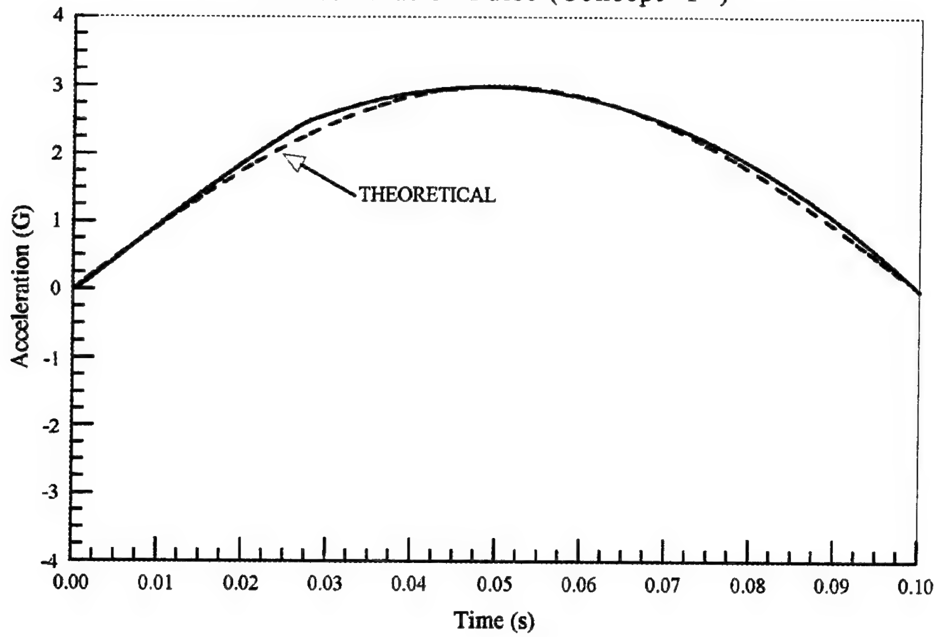
<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type I])

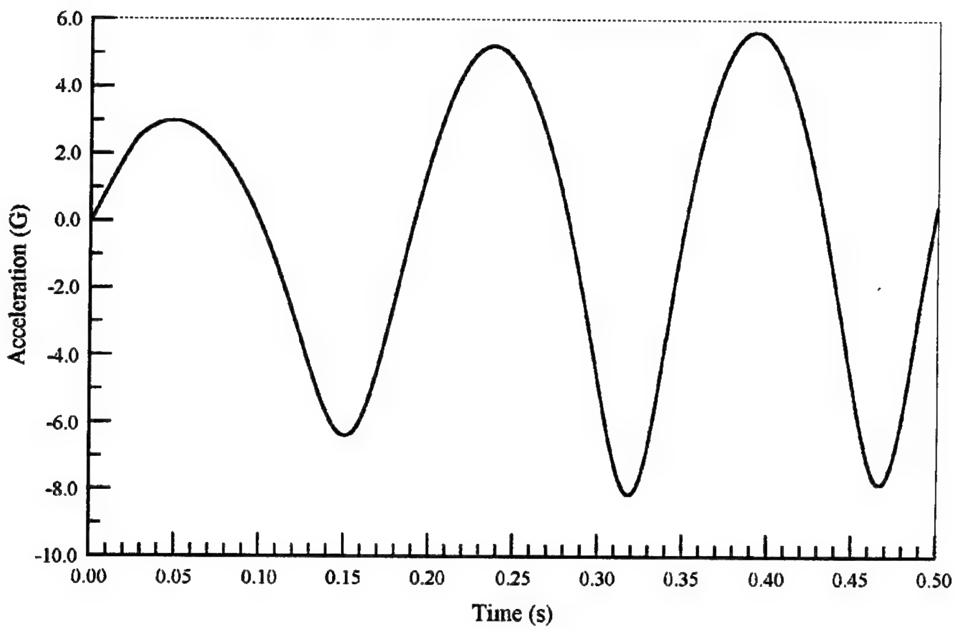
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1350.0 psi
Piston Cylinder Oil Pressure:	800.0 psi
Relief Valve Pressure Setting:	1300.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	3.75 in
Brake Chamber:	3.75 in
Oil Chamber:	12.5 in

3 G Calibration Pulse (Concept "F")





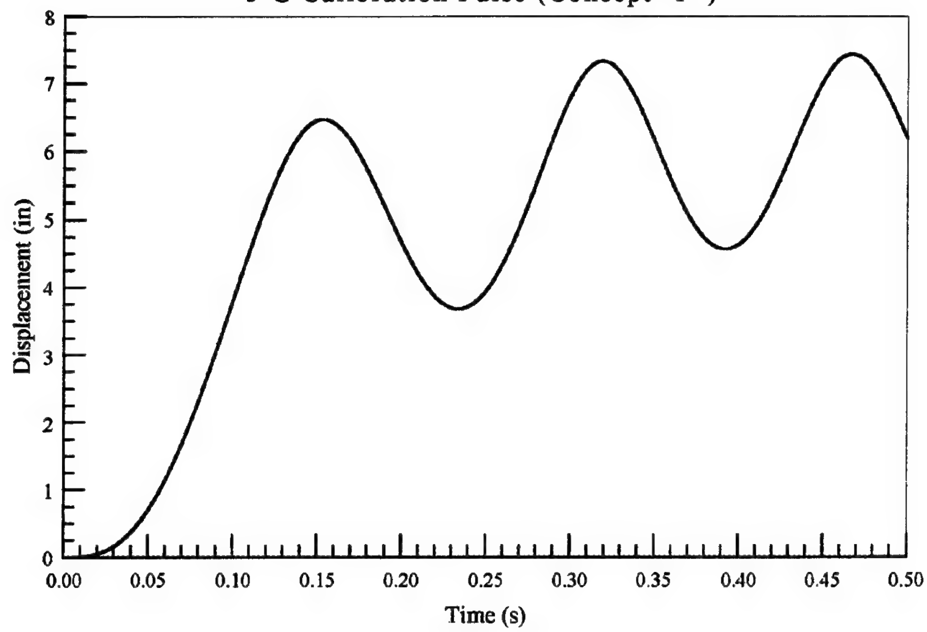
<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type II])

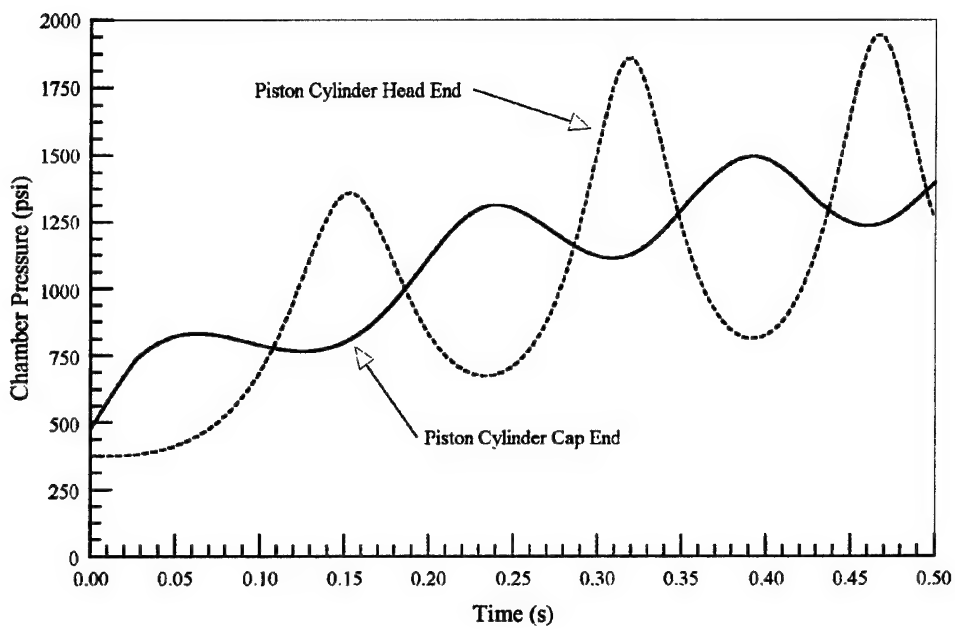
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1400.0 psi
Piston Cylinder Oil Pressure:	375.0 psi
Relief Valve Pressure Setting:	2000.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	3.75 in
Brake Chamber:	10.75 in
Oil Chamber:	5.5 in

3 G Calibration Pulse (Concept "F")





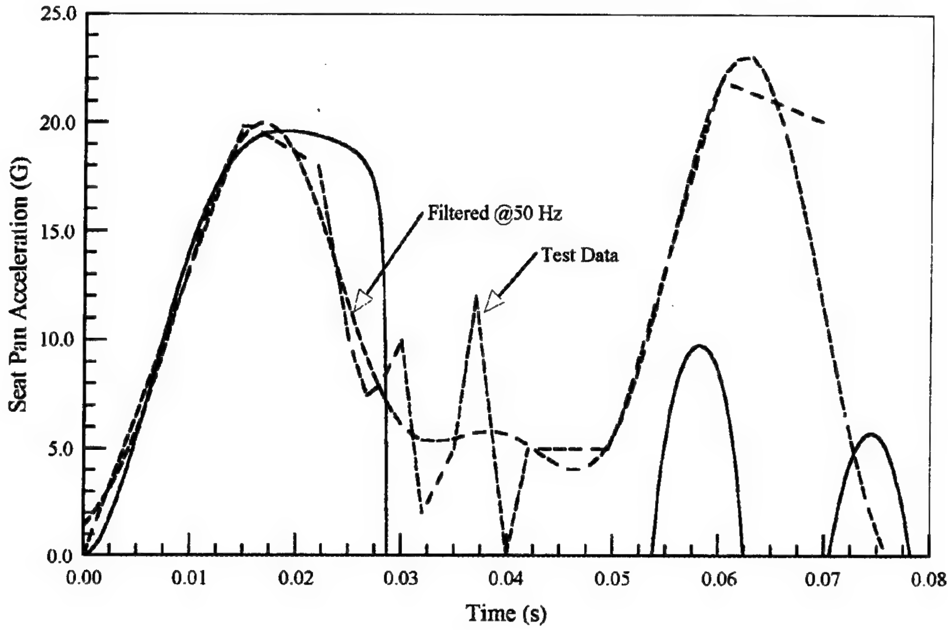
<u>Initial Operating Parameters</u> (3 G -- Calibration Pulse [Type II])

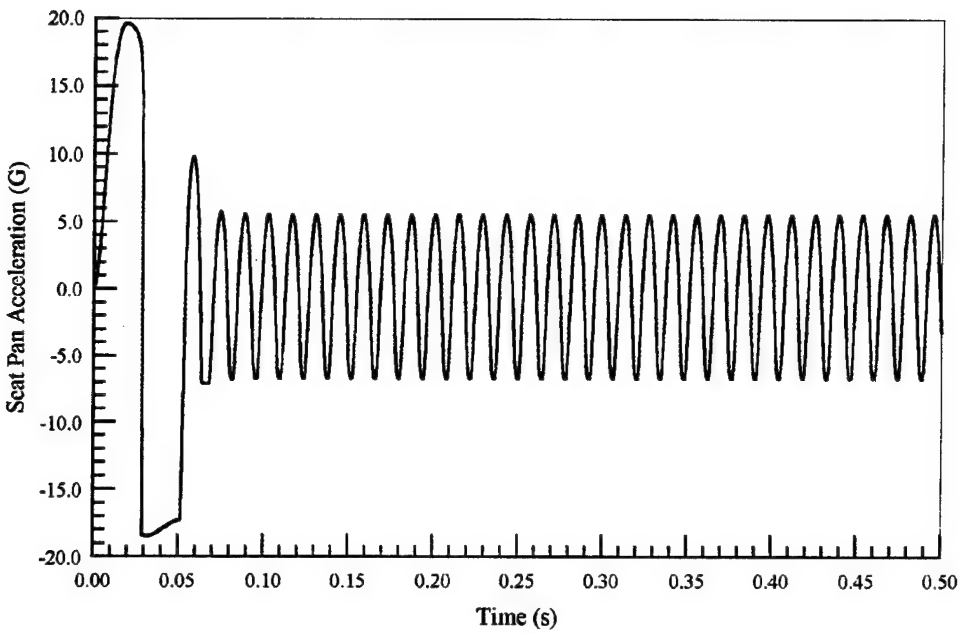
Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	1400.0 psi
Piston Cylinder Oil Pressure:	375.0 psi
Relief Valve Pressure Setting:	2000.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	3.75 in
Brake Chamber:	10.75 in
Oil Chamber:	5.5 in

V-22 Crashworthy Seat (Concept "F")





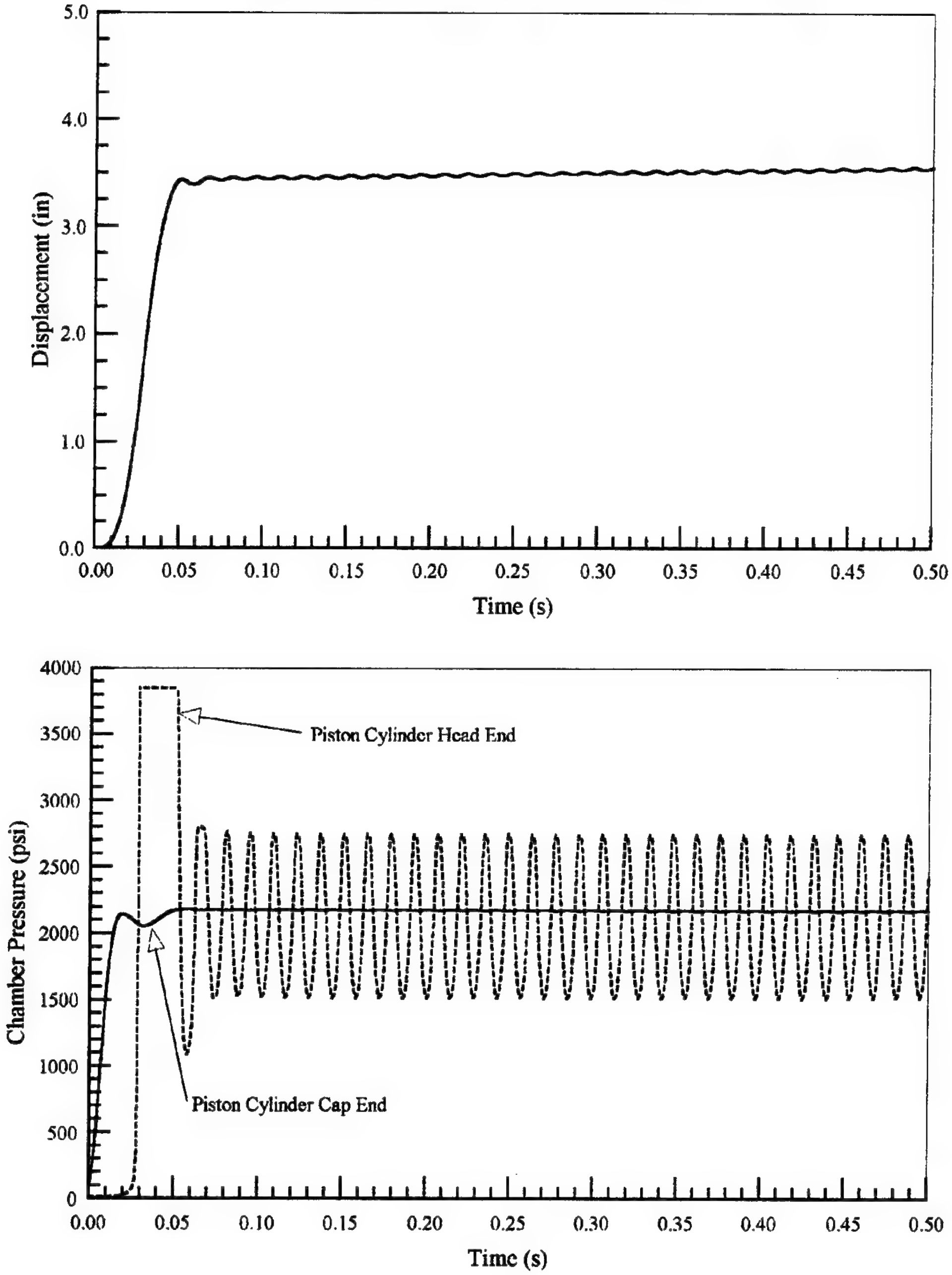
<u>Initial Operating Parameters</u> (20 G – Crashworthy Seating Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2250.0 psi
Piston Cylinder Oil Pressure:	14.70 psi
Relief Valve Pressure Setting:	2500.0 psi

<u>Piston Cylinder Chamber Lengths</u>

Drive Chamber:	3.75 in
Brake Chamber:	1.75 in
Oil Chamber:	14.5 in

V-22 Crashworthy Seat (Concept "F")



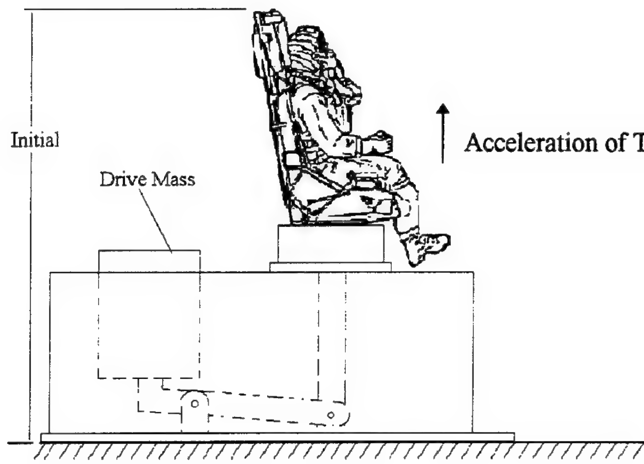
Initial Operating Parameters (20 G – Crashworthy Seating Pulse)

Weight of translating system:	700.0 lb.
Charge Chamber Pressure:	2250.0 psi
Piston Cylinder Oil Pressure:	14.70 psi
Relief Valve Pressure Setting:	2500.0 psi

Piston Cylinder Chamber Lengths	
Drive Chamber:	3.75 in
Brake Chamber:	1.75 in
Oil Chamber:	14.5 in

APPENDIX "F"

Counterweight Driven Platform

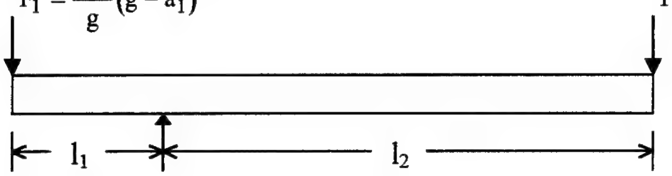


Counterweight Driven Calibration Platform

Given:

1) Platform weight with fixture and manikin = 700 lbs.
2) Required platform acceleration is 3 g.
3) Assume a counter weight of 10,000 lbs.
4) Assume counterweight lever arm is 6 inches.

$$F_1 = \frac{W_1}{g}(g - a_1) \qquad\qquad F_2 = \frac{W_2}{g}(g + a_2)$$



$$\circlearrowright \sum M = 0 = F_1 l_1 - F_2 l_2 \qquad \text{or} \qquad F_1 = F_2 \frac{l_2}{l_1}$$

$$\frac{a_1}{l_1} = \frac{a_2}{l_2} \qquad a_1 = \frac{l_1}{l_2} a_2$$

$$F_1 = W_1\left(1 - \frac{a_1}{g}\right) = W_2\left(1 + \frac{a_2}{g}\right)\frac{l_2}{l_1}$$

$$W_1\left(1 - \frac{l_1}{l_2}\frac{a_2}{g}\right) = W_2\left(1 + \frac{a_2}{g}\right)\frac{l_2}{l_1} \qquad \text{if } a_2 = 3g \text{ then}$$

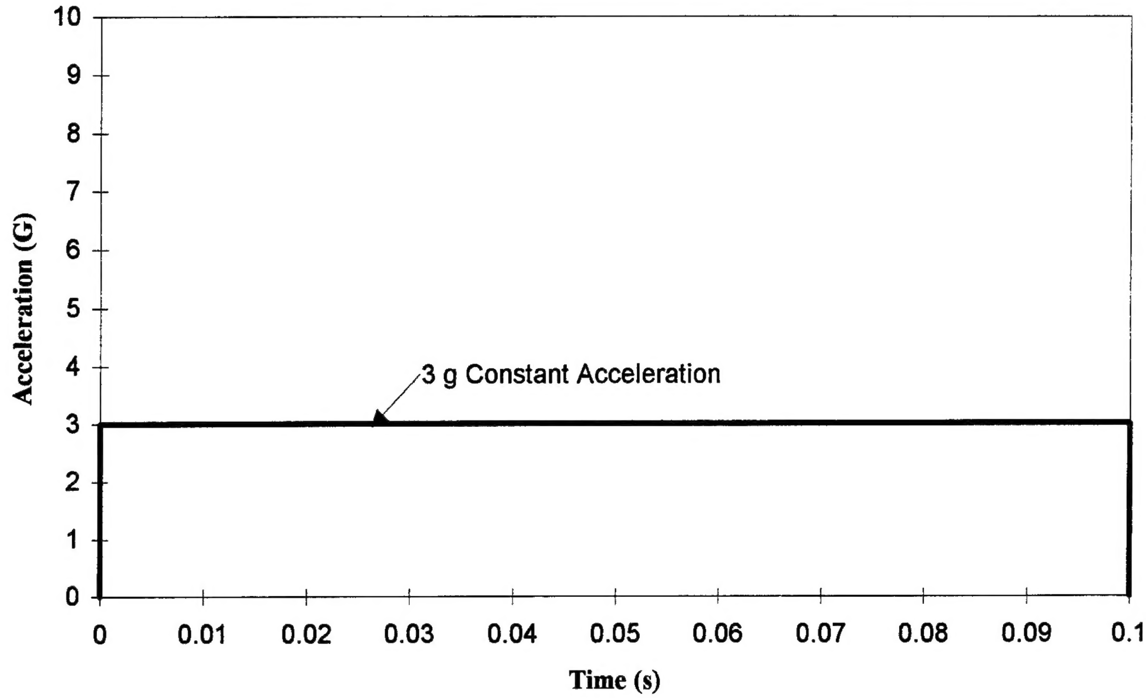
$$W_1\left(1 + \frac{l_1}{l_2}3\right) = W_2(1+3)\frac{l_2}{l_1} \qquad \text{if } W_2 = 700 \text{ lbs and } W_1 = 10{,}000 \text{ lbs then}$$

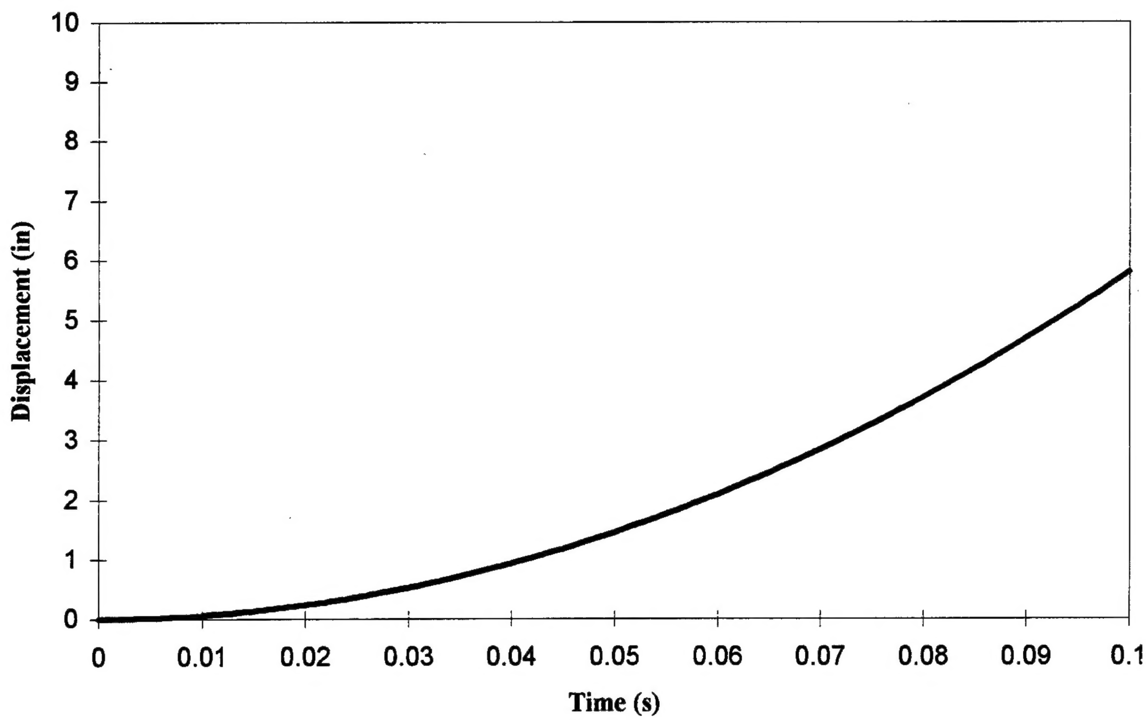
$$10{,}000\left(1 + 3\frac{l_1}{l_2}\right)\frac{l_1}{l_2} = 700(1+3) = 2800$$

$$30{,}000\left(\frac{l_1}{l_2}\right)^2 + 10{,}000\frac{l_1}{l_2} - 2800 = 0 \qquad \frac{l_1}{l_2} = 0.1813$$

$$\boxed{\begin{array}{l}\text{If } l_1 = 6 \text{ inches} \\ \text{then: } l_2 = 33 \text{ inches}\end{array}}$$

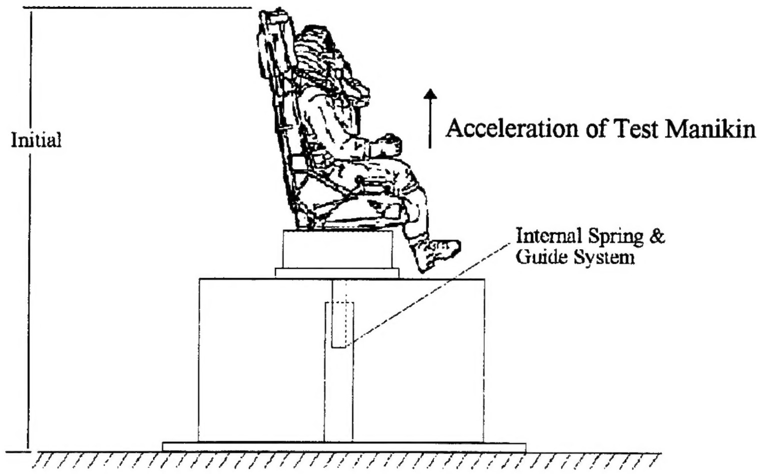
Calibration Pulse (Concept #7)





APPENDIX "G"

Spring Driven Platform



Spring Driven Calibration Platform

Given:

1) Maximum allowable acceleration is 3g.
2) Platform Weight with fixture and manikin = 700 lbs.

Spring Specifications as Follows:

McMaster Carr catalogue part # 9625K18 with spring rate = 40.2 lbs/in.

For 3g Initial Acceleration:

$$F = \frac{W}{g}(g + a) = 4(700) = 2800 \text{ lbs}$$

Spring Deflections:

$$\delta_{total} = \frac{(2800)\text{lbs}}{(4)(40.2)\text{lbs / in}} = 17.4129 \text{ in}$$

$$\delta_{static} = \frac{(700)\text{lbs}}{(4)(40.2)\text{lbs / in}} = 4.3532 \text{ in}$$

$$\delta_{dynamic} = \delta_{total} - \delta_{static} = 17.4129 - 4.3532 = 13.0597 \text{ in}$$

Spring Equation of State:

$$M\frac{d^2x}{dt^2} = -kx \quad \text{where} \quad x = \text{dynamic deflection}$$

$$\text{or} \quad \frac{\delta^2 x}{\delta t^2} + a^2 x = 0 \quad \text{where} \quad a = \sqrt{k/M} = \sqrt{\frac{(4)(40.2)}{700/386.4}} = 9.4213 \text{ sec}^{-1}$$

Therefore, $\mathbf{x = x_o \cos(at) + \delta_{static}}$ where x_o = dynamic deflection

Deflection @ 100 ms:

$$x = 13.0597\cos[(9.4213)(0.1)] + 4.3532 = 12.0333 \text{ in}$$

$$\boxed{\Delta x = 17.4129 - 12.0333 = 5.3796 \text{ in}}$$

Calibration Pulse (Concept #8)